CONNECTING PEOPLE TO THEIR OCEANS: ISSUES AND OPTIONS FOR EFFECTIVE OCEAN LITERACY

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CONNECTING PEOPLE TO THEIR OCEANS: ISSUES AND OPTIONS FOR EFFECTIVE OCEAN LITERACY

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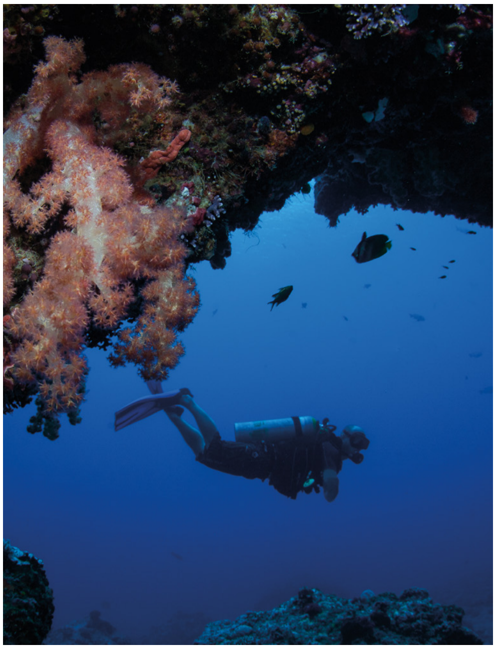

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Table of Contents

04 ***Editorial: Connecting People to Their Oceans: Issues and Options for Effective Ocean Literacy***
Angel Borja, Francesca Santoro, Gail Scowcroft, Stephen Fletcher and Pierre Strosser

06 ***Book Review: Exemplary Practices in Marine Science Education***
Kanesa Duncan Seraphin, Jennifer L. East and Lyndell N. Whitley

09 ***Stepping Out of the Ivory Tower for Ocean Literacy***
Kathrin Kopke, Jeffrey Black and Amy Dozier

22 ***Feasible Options for Behavior Change Toward More Effective Ocean Literacy: A Systematic Review***
Susanne Stoll-Kleemann

36 ***A Change of Mind: Applying Social and Behavioral Research Methods to the Assessment of the Effectiveness of Ocean Literacy Initiatives***
Matthew Ashley, Sabine Pahl, Gillian Glegg and Stephen Fletcher

56 ***Exploring Our Oceans: Using the Global Classroom to Develop Ocean Literacy***
Sarah Fielding, Jonathan T. Copley and Rachel A. Mills

63 ***A System Dynamics Approach to Increasing Ocean Literacy***
Caroline Brennan, Matthew Ashley and Owen Molloy

83 ***University Extension and Informal Education: Useful Tools for Bottom-Up Ocean and Coastal Literacy of Primary School Children in Brazil***
Gabriel Stefanelli-Silva, Juan C. F. Pardo, Paulo Paixão and Tânia M. Costa

91 ***Evaluating Ocean Literacy of Elementary School Students: Preliminary Results of a Cross-Cultural Study in the Mediterranean Region***
Athanasios Mogias, Theodora Boubonari, Giulia Realdon, Monica Previati, Melita Mokos, Panayota Koulouri and Maria Th. Cheimonopoulou

105 ***Building a New Ocean Literacy Approach Based on a Simulated Dive in a Submarine: A Multisensory Workshop to Bring the Deep Sea Closer to People***
Janire Salazar, Carlos Dominguez-Carrió, Josep-Maria Gili, Stefano Ambroso, Jordi Grinyó and Begoña Vendrell-Simón

113 ***The Marine CoLAB: Taking a CoLABorative, Values Based Approach to Connect People to the Ocean***
Rosanna Chambers, Natalie Hart, Sue Ranger, Anna Birney, Corina Angheloiu, Jessica Loring, Sian Williams and Louisa Hooper

119 ***Ocean Literacy to Mainstream Ecosystem Services Concept in Formal and Informal Education: The Example of Coastal Ecosystems of Southern Portugal***
Helena Barracosa, Carmen B. de los Santos, Márcio Martins, Cátia Freitas and Rui Santos

129 ***Ocean Literacy and Knowledge Transfer Synergies in Support of a Sustainable Blue Economy***
Rosa M. Fernández Otero, Georgia A. Bayliss-Brown and Martha Papathanassiou

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EDITORIAL
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Editorial: Connecting People to Their Oceans: Issues and Options for Effective Ocean Literacy

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Editorial on the Research Topic

Connecting People to Their Oceans: Issues and Options for Effective Ocean Literacy

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While there is a growing understanding of theimportance of marine ecosystems for society (Selig et al., 2019), evidence shows that pressures from human activities on these ecosystems are increasing (Korpinen and Andersen, 2016; Lotze et al., 2018), putting the health of marine ecosystems at risk worldwide (Borja et al., 2016). In particular, Sustainable Blue Economy ambitions are becoming an important component of national socio-economic development strategies (e.g., this is called Blue Growth in Europe; Eikeset et al., 2018). This can result in increasing pressures on marine and coastal ecosystems if this development is not designed and implemented with care. Thus, despite current regulatory framework across the globe (illustrated inter alia by the Oceans Act in the USA or Canada and the Marine Strategy Framework Directive in Europe; Borja et al., 2008), it is likely that this challenging situation will continue into the future (Golden et al., 2017).

All citizens are directly or indirectly connected to the marine environment. Ensuring that everyone gains a better understanding of the importance of the oceans, the human-ocean interactions, and opportunities to act sustainably and reduce human impacts on marine ecosystem is central to global Ocean Literacy (Santoro et al., 2017). The Ocean Literacy movement, initiated over 25 years ago in the USA, has received increasing attention world-wide, particularly in Europe, where significant funding had propelled the movement forward. Ocean Literacy is a challenge for all parts of society: educators and trainers, children and professionals, civil society and scientists, consumers and policy/decision makers (Uyarra and Borja, 2016). It is seen as an essential part of the strategies necessary to change human behaviors and practices that can result in healthier marine ecosystems, while allowing sustainable development opportunities (Gelcich et al., 2014). Ocean Literacy will be a key pillar of the upcoming United Nations Decade of Ocean Science for Sustainable Development (2021–2030; Ryabinin et al., 2019).

Two projects, funded by the European Commission's Horizon 2020 program and implemented between 2015 and 2019, focused on challenges and solutions for more effective ocean literacy. The project ResponSEAble[1] investigated how to effectively connect people to their seas and help them better understand the complex human-ocean relationship. This research was intended to identify strategies that will encourage people to make responsible, informed decisions, thus becoming "ocean literate." Its sister project SeaChange[2] explored the way European citizens view

[1] https://www.responseable.eu
[2] https://www.seachangeproject.eu/

their relationship with the sea, by empowering them as "Ocean Literate" citizens, to take direct and sustainable action toward healthy seas and ocean, healthy communities, and, ultimately, a healthier planet.

With this in mind, the editors took the view that a Research Topic in *Frontiers in Marine Science* would be an ideal platform for synthesizing and giving open access to up-to-date research in Ocean Literacy, as developed in the framework of the two EU projects described above and others across the world. This led to the Research Topic presenting a variety of research that addresses issues and options for achieving Ocean Literacy worldwide, which we anticipate will be useful to those involved in the design, implementation, and evaluation of ocean literacy initiatives that target a variety of audiences.

The papers in the Research Topic discuss: (1) practical experiences in Ocean Literacy (formal and informal education for children, training for professionals, tools for raising awareness of consumers, and of investors in the marine sectors), illustrating their effectiveness at catalyzing the transition from "understanding better" to "acting differently" (Barracosa et al.; Fielding et al.; Mogias et al.); (2) the role Ocean Literacy could play through interaction with innovation, regulation, economic incentive, and social norms to support human capital development as a key component of sustainable growth (Fernández Otero et al.); and (3) pre-conditions for effective and increasing Ocean Literacy for different sectors and target groups (Brennan et al.; Chambers et al.). Questions relevant to Ocean Literacy include: Which knowledge (produced by whom) to share and how? (Salazar et al.; Kopke et al.); Who to target and how to effectively reach those targeted? (Seraphin et al.; Stefanelli-Silva et al.); How to design Ocean Literacy initiatives, including by mobilizing those targeted (e.g., via living lab approaches), to ensure effective Ocean Literacy and pave the way for behavior change? (Ashley et al.; Barracosa et al.; Stoll-Kleemann et al.); What are the knowledge gaps that limit our capacity to design effective Ocean Literacy initiatives, connecting people to the Ocean? (Chambers et al.). As scientists, it is likely you can discover many more questions discussed in this Research Topic.

We thank all contributing authors and are confident that you will enjoy reading these papers on Ocean Literacy. We hope that the papers will support progressive changes to improve understanding of the oceans and seas and their processes, ultimately leading to a healthier ocean.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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BOOK REVIEW
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Book Review: Exemplary Practices in Marine Science Education

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Keywords: ocean literacy, identity, education, environment, marine science

A Book Review on
Exemplary Practices in Marine Science Education

Geraldine Fauville, Diana L. Payne, Meghan E. Marrero, Annika Lantz-Anderson, and Fiona Crouch (Cham, Switzerland: Springer), 2018, 452 pages, ISBN: 9783319907772.

Humans and the ocean are inextricably interconnected. The ocean drives the water cycle, governs climate, and provides a diverse number of ecosystem services (Barbier et al., 2012). Modern societies are not only physically connected by the ocean, but they also depend on and are shaped by it. Moreover, just as the ocean has influenced humankind, so too have we impacted the ocean and the systems within it—initiating the Anthropocene Epoch (Steffen et al., 2011).

There is a need for the global public to develop a better (1) understanding of how the ocean functions, (2) ability to communicate about the ocean, and (3) capacity to make informed decisions about its resources. Education is one of the most important tools available to support the growth of ocean literacy on a global level. As we embark on missions to improve public understanding of the ocean, it is critical to reflect on and learn from prior research and programs.

In 2018, Fauville et al. published the first international book on marine science education and ocean literacy. Our review examines the contents of this edited volume, which contains 24 contributed chapters. Fauville et al. (2018) begin with the history of ocean literacy, which is defined as a person's understanding of the ocean's influence on them and their influence on the ocean (Schoedinger et al., 2010). The introduction details many of the challenges inherent in communicating ocean and marine science. For example, the public not only lacks familiarity with the environment, but marine ecology is also inherently complex. Moreover, the tangle of social, financial, and political issues associated with marine resources makes communication and productive discourse difficult. In addition, misinformation is easily spread in this modern, digital age—impeding people's ability to assess the accuracy of information (Thaler and Shiffman, 2015).

The collected chapters synthesize research from the marine science education field, providing both a historical perspective and a road map for future research. Readers are encouraged to use the authors' examples as models for their own communities, needs, and interests. Throughout the chapters, there is an emphasis on the need to share data across the global marine science education community. Readers are encouraged to join the international network of scholars, educators, and citizens working to advance participation in marine science education and conservation. The majority of the book is split into two sections: research and practice. The collected works describe research and interventions across age levels, social demographics, educational settings, and literacy levels.

Research and evaluation studies shared in the book reflect different methods to achieve marine science education outcomes in both formal and informal educational settings. For example, Niedoszytko et al. (2018) report on a 12-year program exploring the integration of a combined formal-informal program related to the Baltic Sea. The longitudinal project targeted youth 6

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times during their education journey, from ages 6 to 17 years, and included evaluation of student experiences, marine education, and ocean literacy. Walters and Bishop (2018) use research by Almarode et al. (2014) to support the causal connection between students' feelings of intellectual capacity in Science, Technology, Engineering, and Mathematics (STEM) and future career choices. Riedinger and Taylor (2018) discuss the body of research on field trips' influence on student interest and attitudes (Behrendt and Franklin, 2014) and provide suggestions for effective field trips, highlighting practical concerns such as the preparation of chaperones. Robinson and Murray (2018) speak to the importance of evaluating programs and discuss science communication theory, providing examples from the National Marine Aquarium in the United Kingdom.

For practitioners, there are examples of programs developed, implemented, and evaluated in various educational settings and several countries. Readers will likely appreciate the descriptions of how programs were designed and implemented as well as strategies for assessing success and evaluating programs. Respected authors share their experience over many years as marine science education researchers, practitioners, or both. The scope of programs presented spans a wide range and includes connecting graduate students with K-12 classrooms, leveraging parent chaperones, conducting professional development, assessing longitudinal studies of aquarium visitors, engaging citizen scientists, providing meaningful field experiences, and teaching in multicultural settings—all in the context of ocean literacy. Across programs, there is a shared goal to create positive connections as well as a sense of responsibility and stewardship for the ocean environment. Authors urge the cultivation of empathy toward marine life and how it is researched.

Another recurring theme across the practitioner section is the integration of modern cultural influences on ocean literacy. The collected works repeatedly advocate for creatively pushing the boundaries of traditional science education. Jaksha (2018), for example, presents the idea of ocean identity, a concept derived from environmental identity (Payne, 2000), as an index to quantify the combination of emotion, feelings, and connections that predict a person's actions and behaviors. Other authors also emphasize the need to move beyond campaigns that stimulate interest and knowledge—toward programs that involve more participatory conservation and problem-solving strategies. The use of appropriate role models is another uniting theme across chapters. Authors, like Brill et al. (2018), advocate getting experts out of the ivory tower and into the classroom. Similarly, the importance of providing students and the public with authentic research experiences is covered in multiple chapters, from biofilm and biodiversity projects targeting primary school students and teachers in Sweden, the United States, and Norway (Frederick et al., 2018), to ocean-access projects for socially disadvantaged participants of all ages in the United Kingdom (Baker and Readman, 2018), to general information on meaningful watershed educational experiences in the United States (Nuss et al., 2018).

The collected chapters are optimistic, and yet they are also written with a sense of urgency. The writing itself is easily accessible and provides a useful history and context to ocean literacy. The authors cover issues in formal, informal, and community settings across several countries and cultures. It is recommended as a resource for educators and researchers of marine science as well as other science education disciplines.

AUTHOR CONTRIBUTIONS

KS coordinated the book review writing, editing, and submission. JE and LW both provided substantial contributions to the writing and revision of the article.

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Stepping Out of the Ivory Tower for Ocean Literacy

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The Ocean Literacy movement is predominantly driven forward by scientists and educators working in subject areas associated with ocean science. While some in the scientific community have heeded the responsibility to communicate with the general public to increase scientific literacy, reaching and engaging with diverse audiences remains a challenge. Many academic institutions, research centers, and individual scientists use social network sites (SNS) like Twitter to not only promote conferences, journal publications, and scientific reports, but to disseminate resources and information that have the potential to increase the scientific literacy of diverse audiences. As more people turn to social media for news and information, SNSs like Twitter have a great potential to increase ocean literacy, so long as disseminators understand the best practices and limitations of SNS communication. This study analyzed the Twitter account of MaREI – Ireland's Centre for Marine and Renewable Energy – coordinated by University College Cork Ireland, as a case study. We looked specifically at posts related to ocean literacy to determine what types of audiences are being engaged and what factors need to be considered to increase engagement with intended audiences. Two main findings are presented in this paper. First, we present overall user retweet frequency as a function of post characteristics, highlighting features significant in influencing users' retweet behavior. Second, we separate users into two types – INREACH and OUTREACH – and identify post characteristics that are statistically relevant in increasing the probability of engaging with an OUTREACH user. The results of this study provide novel insight into the ways in which science-based Twitter users can better use the platform as a vector for science communication and outreach.

Keywords: ocean literacy, science communication, public engagement, Twitter, social networking sites, sentiment analysis

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INTRODUCTION

Education is a fundamental pillar of environmental stewardship and a motivator of behavioral change (Steel et al., 2005; Potts et al., 2016). An understanding of marine processes and issues is necessary to effectively engage in discussions of marine policy and encourage adoption of pro-environmental behaviors (Steel et al., 2005; McKinley and Fletcher, 2010; Chen and Tsai, 2016; Easman et al., 2018). It is widely recognized that human activities are threatening the integrity of the marine environment (Jefferson et al., 2015; Chen and Tsai, 2016; Easman et al., 2018; Lotze et al., 2018). However, the most pressing threats to marine ecosystems are not always well understood by the general public (Jefferson et al., 2014; Lotze et al., 2018). This lack of understanding presents a significant barrier to transforming scientific research into positive social change, and demonstrates a need to work toward improving the general public's familiarity with ocean-related issues.

Between 2002 and 2010, a group of educators and scientists established a definition and framework for ocean literacy (OL) (Schoedinger et al., 2010). The framework identifies an ocean literate person as (1) knowledgeable about the ocean, (2) able to communicate about the ocean in a meaningful way, and (3) able to make informed and responsible decisions regarding the ocean and its resources (Cava et al., 2005; Santoro et al., 2017). The goal of improving the public's OL is to create societies that understand their interconnected relationship with the ocean, enhancing their ability to make informed and responsible decisions about marine resources (Santoro et al., 2017). Therefore, it is imperative that OL topics are communicated in a fashion that enables citizens to both understand the information and apply it to make environmentally friendly decisions (**Figure 1**).

Today's educators have a wide variety of contemporary media platforms to disseminate knowledge and increase public OL. Social networking sites (SNSs) have become an increasingly relied-upon source of information and news (Kwak et al., 2010; Stieglitz and Dang-Xuan, 2013; López-Goñi and Sánchez-Angulo, 2017). A 2017 PEW Research Center survey of United States adults reported that 67% of Americans get at least some of their news from SNSs like Twitter, Facebook, and YouTube (Kane et al., 2012; Gottfried and Shearer, 2017). In light of this, SNSs like Twitter can be powerful platforms for communicating science, including OL topics. Using the appropriate techniques, ocean scientists and research centers should be able to harness the potential of SNSs to engage with wider audiences (Fauville et al., 2015; López-Goñi and Sánchez-Angulo, 2017).

In response to the increase in SNS popularity, individual scientists, research centers, and academic institutions are now frequently turning to Twitter to publicize scientific events and journal publications (Eysenbach, 2011; Peoples et al., 2016), and to communicate with their peers about science and research (López-Goñi and Sánchez-Angulo, 2017; Didegah et al., 2018). Twitter is also perceived by many scientists and research centers as a platform that can support science communication efforts with non-scientific audiences (López-Goñi and Sánchez-Angulo, 2017; Côté and Darling, 2018b; Didegah et al., 2018). As a result, scientists from diverse disciplines have analyzed Twitter to better understand how users interact and exchange information (Kwak et al., 2010; Stieglitz and Dang-Xuan, 2013; Didegah et al., 2018). Twitter's information-sharing process of 'retweeting,' in addition to its 'like,' 'tag' and 'hashtag' features and the 'comment' function, provide quantifiable metrics for investigating information diffusion on Twitter, which is constantly and continuously collated. This information is readily accessible via Twitter's Application Programming Interface (API) (Kwak et al., 2010; Stieglitz and Dang-Xuan, 2013; López-Goñi and Sánchez-Angulo, 2017).

Twitter users can freely follow others and interact with their posts. However, interpersonal networks on Twitter are subject to homophily, a social phenomenon in which users limit their associations to individuals with similar sociodemographics, behaviors, and perspectives (McPherson et al., 2001; Aiello et al., 2012; Fauville et al., 2015). Several studies have highlighted that Twitter users preferentially follow those that are perceived to have similar interests and shared views (Yardi and Boyd, 2010; Conover et al., 2011; Faralli et al., 2015; Šćepanović et al., 2017; Côté and Darling, 2018b) – a tendency referred to as "in-group favoritism" (Everett et al., 2015). Côté and Darling (2018b) analyzed the Twitter networks of 110 scientists and found that scientists with fewer followers were mainly followed by other scientists. However, their results showed that the heterogeneity of user types following a scientist – e.g., politicians, non-profits, and journalists – drastically increased for scientists with over 1000 followers. The study concluded that tweeting scientists can indeed reach different and new audiences, so long as they work to develop a large-enough network (Côté and Darling, 2018b).

Twitter's 'retweet' feature has been used in several studies as a metric to gauge the extent of a post's reach, particularly in relation to post characteristics such as 'hashtags,' 'mentions,' photos, or online links that could potentially increase retweet frequency (Nagarajan et al., 2010; Suh et al., 2010; Yang and Counts, 2010; Macskassy and Michelson, 2011; Garimella and Weber, 2017). Conover et al. (2011) demonstrated that Twitter users predominantly retweet users with similar views, reiterating the prevalence of homophily and in-group favoritism in Twitter interactions. In addition, many studies have investigated the degree to which language influences a tweet's engagement. For example, Stieglitz and Dang-Xuan (2013) highlighted the relevance of sentiment in Twitter posts and found that the use of emotional rather than neutral language within tweets influenced the rate of retweets.

Previous research substantiates the notion that Twitter has great potential for science communication in support of ocean literacy, while highlighting that tweeting itself may not be enough to reach intended audiences. There exists a gap in the literature concerning how often tweets from scientists are engaged by different types of users (Côté and Darling, 2018b). A better understanding of how different Twitter users interact with science-based tweets could increase scientists' capacity to disseminate their work on Twitter and proliferate scientific literacy. Here, we explore the association between the characteristics of an OL-based tweet and users' engagement, measured in retweets, by analyzing the Twitter account of Ireland's Centre for Marine and Renewable Energy (MaREI). The objectives of this study are twofold:

(1) Determine if MaREI's OL posts reach audiences that may not already be familiar with the subject matter and,
(2) Identify how MaREI's OL posts could be adapted to increase their reach and engagement with wider and more diverse audiences.

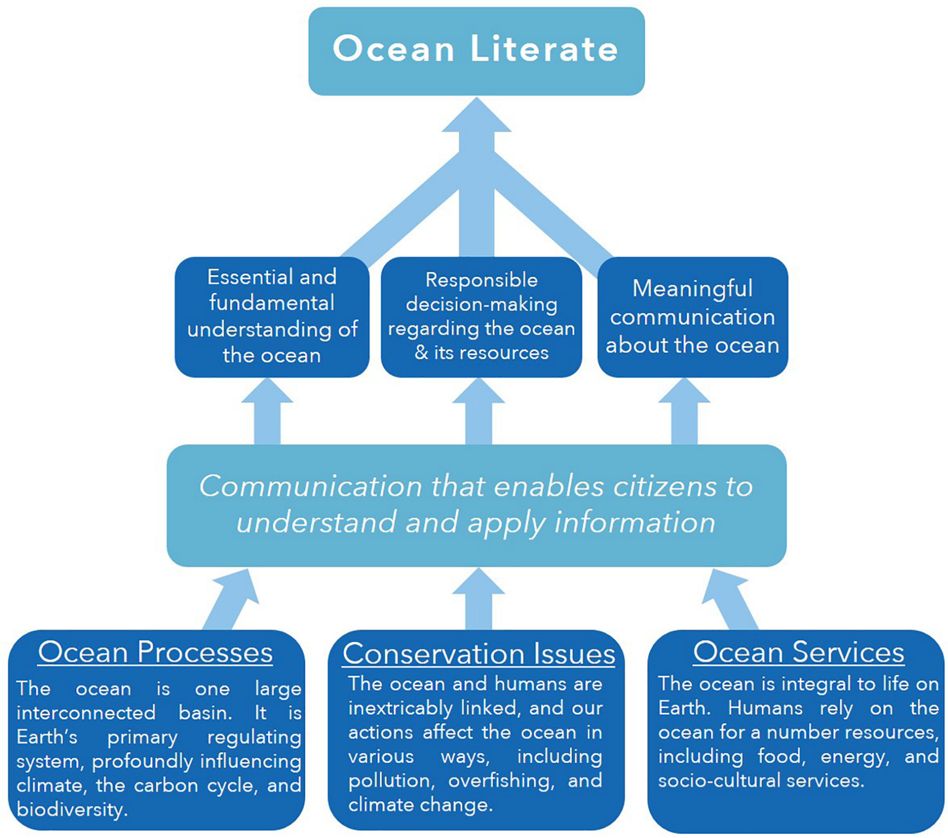

FIGURE 1 | Ocean Literacy Development Framework. The schematic demonstrates the three themes used to identify an ocean literacy post – Ocean Processes, Conservation Issues, and Ocean Services – and highlights the three key principles that define an ocean literate person. Altogether, **Figure 1** represents a conceptual framework by which marine science communication results in an ocean literate person (Schoedinger et al., 2010).

MATERIALS AND METHODS

Case Study: MaREI Centre

MaREI is a research center focusing on the marine environment, renewable energy, and climate action. The center combines the expertise of a wide range of research groups and industry partners with the shared mission of addressing the main scientific, technical and socio-economic challenges in the marine and renewable energy sectors. MaREI is a Science Foundation Ireland research center coordinated by the Environmental Research Institute (ERI) at University College Cork, Ireland, and has over 200 researchers working across 6 academic institutions collaborating with more than 45 industry partners.

MaREI is well represented on Twitter (@MaREIcentre), with just over 4,000 organically grown followers and almost 9,000 tweets to date, including 700 photos and videos (as of December 2018). MaREI regularly uses social media to promote research and to disseminate information, particularly to support societal engagement on grand challenges relating to energy, climate action and sustainable marine development. The institute's OL Twitter posts have the ultimate goal of increasing awareness of the value of the world's oceans and the need to safeguard them for future generations through the provision of accessible information. The center's commitment to scientific communication and the proliferation of OL, especially on Twitter, makes it an ideal case study for the purposes of this paper.

Twitter Analytics Data and User Classification

To obtain a sufficient sample size, tweets were collated over a 21-month period, January 05, 2017–September 13, 2018, using administrative access to MaREI's Twitter account. Our analysis focused on original tweets that expressed educational themes and analytical information associated with ocean processes, functions, and urgent conservation issues – relating to the definition of an individual that is ocean literate. Posts about other topics, e.g., promoting conferences, talks, or job opportunities, were manually filtered and omitted from final analyses. Filtering irrelevant tweets ensured results reflected user behavior associated with OL posts only. From the initial 1080 tweets collected over the defined study period, 257 demonstrated OL themes. Relevant posts were considered direct attempts from MaREI to promote OL via Twitter.

A number of previous studies have demonstrated the influence of post characteristics on retweet behavior (Stieglitz and Dang-Xuan, 2013; Hales et al., 2014; Diug et al., 2016; Brady et al., 2017; Wadhwa et al., 2017). Researchers have explored unique vectors of impact variables, resulting in a diverse range of variables being used across studies. Drawing from the literature (Suh et al., 2010; Stieglitz and Dang-Xuan, 2013; Wadhwa et al., 2017), this study selected five variables to explain users' retweet behavior:

- Number of Photos
- Number of Mentions
- Number of Hashtags
- Number of URL links
- Semantic Orientation

In addition to demonstrating the relationship between post characteristics and overall retweet frequency, this study looked to understand how post characteristics influenced the likelihood a tweet was retweeted by users dissimilar to MaREI. Representing this relationship highlights variables important in reaching users outside of MaREI's immediate network. To test this, a binary dependent variable, REACH, was defined by classifying users as one of two types:

- INREACH (0)
- OUTREACH (1)

MaREI's INREACH group was defined as users whose profiles expressed similar interests (Weng et al., 2010; Hanusch and Nölleke, 2018), and therefore most likely already have some understanding of ocean-related issues, i.e., maintain a degree of ocean literacy. Based on the identity of MaREI, we identified three types of like-minded users, and then combined them into one group to make up MaREI's INREACH faction: marine scientists, academics, and marine enthusiasts. Marine scientists were identified as users that stated they were involved in marine-related research, such as offshore wind energy, or marine ecology. We identified academics as users – either individuals or institutions of higher learning – that were associated with some kind of science, tertiary education, or possessed advanced degrees. Including academics in this way ensured our INREACH group captured the tendency of scientists and academics to operate within an "echo-chamber," preferentially interacting with others in the same discipline or within the realms of advanced education (e.g., universities and research centers). Lastly, we identified marine enthusiasts as users that operate outside the confines of science and research, yet undoubtedly possess some level of understanding of marine-related issues given their careers, interests, and values. For example, a user whose profile bio expresses a love for sailing catamarans may not be involved in marine research or academia, yet their interest in marine activities provides an indication that they are familiar with ocean-related issues (Li et al., 2014). All users that did not fit into our INREACH group were subsequently classified as part of MaREI's OUTREACH group (**Figure 2**). The binary classification scheme captures the inherent tendencies of in-group favoritism and homophily, where users implicitly favor others with similar interests and predominantly interact with others within the same network. However, it is important to note that in-group favoritism and homophily were not directly quantified in this study- such measures are beyond the scope of this paper's objectives.

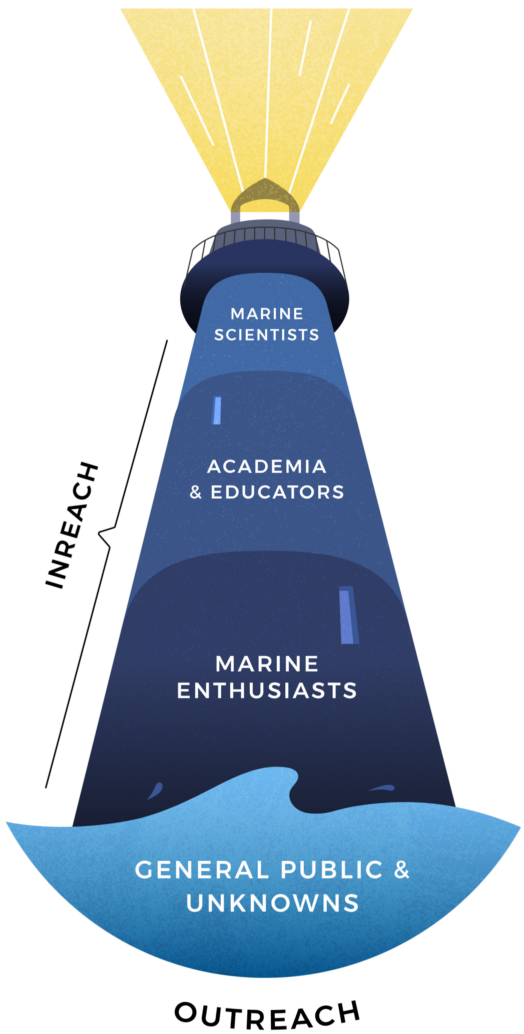

FIGURE 2 | User classification scheme. An artistic visualization of the INREACH–OUTREACH classification, emulating the tendency of marine science communication to circulate within a defined, like-minded network (represented by the lighthouse).

To separate MaREI's INREACH-OUTREACH groups, we obtained the biographical information publically available in the Twitter bios, usernames, and handles of each user that retweeted an OL themed post. Biographical user-related data provides one of the most accurate depictions of a user's true identity (Wagner et al., 2012), and was therefore the primary basis for our classification scheme. Rooted in previous methodologies (Barthel et al., 2015; Priante et al., 2016; Côté and Darling, 2018a,b), we built a pre-defined keyword and expression string list using words that related to our INREACH classification group, and were therefore likely to be mentioned in a user's biographical data (**Table 1**). The "stringr" package (Wickham, 2017) in R was used to filter user profiles that contained relevant keywords and expressions. The most notable additions made to Côté and Darling's (2018a) search string were context-relevant words to improve classification accuracy. For example, in addition to including words such as 'university' and 'college,' the acronyms of prevalent universities in Ireland were also included, such as 'UCC,' 'CIT,' and 'NUIG.'

The accuracy of our keyword-based user classification scheme was determined by manually checking the profiles of a random subsample (∼10%) of users, from which the assigned classification was either verified or not. In our subsample, the classification scheme returned a precision rate of 85% – a success rate in line or better than similar studies that conducted user classification analysis on Twitter (Wagner et al., 2012; Barthel et al., 2015; Priante et al., 2016; Côté and Darling, 2018b; Haustein, 2018). The simple dichotomous categorization scheme greatly reduces the risk of misclassification, however, the algorithm is not without limitations. Our consortium does not account for profiles in languages other than English, nor does it detect emoticons. The greatest challenge using the keyword approach was identifying INREACH users that either did not identify themselves as such in their bios, or whose bios were left blank. We addressed this by further analyzing users' usernames and handles, which provided a means to apply the keyword search to classify profiles with blank bios. While this method enabled the accurate classification of a number of profiles (e.g., @tony**ocean**ork, @ireland**ocean**, and @newtrients**_ucc**) it is possible that certain OUTREACH users belonged with the INREACH group. Without directly approaching and asking users who they are, we have no means to calculate this error. That being said, previous studies have shown that Twitter users, particularly scholars, typically reveal their professional personas in their user-related data (Chretien et al., 2011; Haustein, 2018). For example, Bowman (2015) found that 87% of surveyed university professors mentioned both their place of work and their professional title in their Twitter profiles. This shows that, while imperfect, the methodology used was the most appropriate for this study's purposes, and capitalizes on the limited information available on users' profiles.

TABLE 1 | Categorization of MaREI's INREACH–OUTREACH groups using regular expression searches.

Classification of INREACH–OUTREACH users		
Network category	**Identity**	**Example keywords**
INREACH	Marine Scientists – users involved in marine-related research and science	Ocean + law, ocean + literacy, fisheries, hydro + energy
	Academia – users associated with science, universities, and interdisciplinary research centers	STEM, researcher, Ph.d., university
	Marine Enthusiast – users that express an interest and/or familiarity of marine activities	scuba, sail.*, *ocean.*,
OUTREACH	All users outside of MaREI's inreach network, e.g., government officials, and general public profiles	No keywords present in the user's biographical data

The Table includes the common symbols and syntax used in regular expression, e.g., '' matches zero or more occurrences of any preceding character string.*

Sentiment Analysis

The emotional orientation of the text in each tweet was analyzed using computer-based sentiment analysis (SA). SA – also known as opinion mining – provides insight to the semantic expression of a string of words, and can be used to define the polarity of a tweet, i.e., how positive or negative a tweet is given its word choice (Medhat et al., 2014). The popularization of SNSs as platforms for information diffusion has made Twitter a common medium for the application of SA (Agarwal et al., 2011; Bollen et al., 2011; Saif et al., 2012; Ferrara and Yang, 2015a,b; Nakov et al., 2016).

There are two prominent automatic classification techniques used to extract semantic expression in short text sequences: lexicon-based analysis and machine learning analysis. Each enables a respective degree of granularity, and varies in performance given the context to which it is applied. Therefore, it is important to account for circumstance and objective when selecting the appropriate SA approach. This study used a Lexicon-based classification technique, which extracts semantic orientation using a pre-defined word list. Several word list functions exist, including AFINN, SentiStrength, and OpinionFinder (Bravo-Marquez et al., 2013). The words included in each lexicon vary, most notably regarding strong obscene words and common informal online slang, such as 'lmao' and 'wtf.' For the purposes of our analysis, AFINN was deemed the most appropriate word list function.

The AFINN sentiment lexicon was developed by Finn Årup Nielsen between 2009 and 2011, and is a manually constructed list of English words that rate valence on an integer scale between −5 (negative) and ++5 (positive). Nielsen (2011) built the initial AFINN lexicon using topical tweets about the United Nations Climate Conference (COP15) in 2009. The latest version of the lexicon contains 2477 unique words and 15 phrases, including informal Internet slang, and is currently one of the most comprehensive lexicons for Twitter-based SA (Koto and Adriani, 2015).

The polarity of a tweet was measured by summing the valence of its linguistic structure, demonstrated by:

$$P_t = \sum pos_w + \sum neg_w,$$

where P_t is the overall polarity of a tweet as a function of the summation of the degree of valence of each word in a tweet. The result demonstrates the emotional orientation of a tweet, i.e., positive or negative, as well as the relative strength. **Table 2** shows examples of the AFINN lexicon as applied to OL tweets collected from MaREI.

Regression Analysis

Regression analysis is the primary technique for identifying variables associated with a tweet's level of user engagement (Suh et al., 2010; Hong et al., 2011; Wadhwa et al., 2017). Regression models derive the degree of correlation between a set of covariates and a dependent variable, highlighting instances of

TABLE 2 | Sample tweets demonstrating the AFINN sentiment score methodology.

Example tweets and corresponding sentiment scores		
(Number.) Tweet text	**Words (valence)**	**Aggregate Polarity**
(108) More than **happy** to **support** such a **great** community-led initiative! **Delighted** to see it take off with so much **support. . .hopefully** it will be an **inspiration** and model for other communities. Check out this **brilliant** new Plastic **Free** Festival Guide	Happy (3) Support (2)* Great (3) Delighted (3) Hopefully (2) Inspiration (2) Brilliant (4) Free (1)	20
(87) The record-breaking marine heatwave in 2016 across the Great Barrier Reef has left much of the coral ecosystem at an "unprecedented" **risk** of **collapse** according to a new study published in Nature. 94% of reefs surveyed were affected	Risk (−2) Collapse (−2)	−4
(192) Sea **strike**! **Light-hearted** animation reminding us to take **better care** of our oceans #WorldOceansDay	Strike (−1) Light-hearted (1) Better (2) Care (2)	4

* *If a word was used twice in a tweet, AFINN only scores it once, e.g., 'support' in tweet 108 was counted only once. Bolded words represent that triggered the AFINN lexicon. Corresponding valence scores are presented in the adjacent column.*

TABLE 3 | Variables included in each regression model.

Regression variables		
Variable	**Description**	**Measurement form**
User Behavior		
Retweets	Total number of retweets per tweet	Positive integer
Reach	Binary classification identifying posts that were retweeted by outgroup user	1 = outreach post 0 = inreach post
Photos	Total number of photos in the tweet	Positive integer
Mentions	Total number of users mentioned in the tweet	Positive integer
Links	Total number of links in the tweet	Positive integer
Hashtags	Total number of hashtags in the tweet	Positive integer
Sentiment (AFINN)	Aggregate sentiment score for tweet	Integer

variable dependency. To improve the accuracy of predictions, models must appropriately account for the types of variables used and any sampling bias (McCullagh, 1980). In this study, the RETWEET and REACH vectors differ in their dependent variable structure, necessitating the application of a negative binomial regression and a multivariate logistic regression, respectively. The variables used in the regression analyses are explained in **Table 3**.

Negative Binomial

Retweet frequency for OL posts, demonstrated by the dependent variable RETWEET, represents true-event count data, where an event is expressed only as a non-negative integer value. For example, a post could not be retweeted half a number of counts, nor could it be retweeted less than zero counts. As typical with true-event count data, the RETWEET variable's conditional variance is greater than its mean, and therefore requires an adjustment in analysis to account for over-dispersion (Gardner et al., 1995; Ver Hoef and Boveng, 2007). For these reasons, a negative binomial (NB) model was used to represent the data's distribution. Retweet behavior was defined by the following regression:

$$\log(E(R_n)) = \beta_0 + \beta_1 photos + \beta_2 mentions + \beta_3 links + \beta_4 hashtags + \beta_5 afinn,$$

where $E(R_n)$ is the expected number of retweets for the study's vector of explanatory variables as defined by a set of explanatory variables, β_i.

Multivariate Logistic Regression

Multivariate logistic regression (MLR) is a robust technique for understanding the relational strength of a set of explanatory variables with a binary response (Pregibon, 1981). In this case, our binary response variable, REACH, classified collated OL themed posts based on whether or not at least one OUTREACH user retweeted that post. After consulting our user classification algorithm, which was run for every unique user that retweeted, we assigned a "1" for posts that were retweeted by at least one OUTREACH user, or a "0" for posts that were retweeted by INREACH users only (**Table 3**). The resulting model estimates the probability of an OL themed post being retweeted by an OUTREACH user as a function of a set of specified post characteristics.

Estimating a function's coefficients, β_j, is most commonly done using the maximum likelihood method, which derives parameter values by maximizing the probability of reproducing the values of the observed data set given a selected model (Peng et al., 2002). The following regression was used to define variables associated with a tweet's REACH:

$$\text{logit}(E(O_n)) = \beta_0 + \beta_1 photos + \beta_2 mentions + \beta_3 links + \beta_4 hashtags + \beta_5 afinn,$$

where $E(O_n)$ is the estimated probability of reaching a user outside of MaREI's classified INREACH group.

RESULTS

User Classification

A total of 444 unique users retweeted OL posts from MaREI over the defined study period. Using our pre-defined keyword list, we identified 289 (65%) users as part of MaREI's inreach group, and 154 (35%) users as part of the outreach group. **Table 4** provides examples of classified users, highlighting the words in each profile that triggered the algorithm's demarcation of INREACH (TRUE). Profiles that did not contain a keyword were labeled as OUTREACH (FALSE).

TABLE 4 | Examples of the users and the classification scheme.

User classification			
Handle	**Username**	**Bio**	**INREACH (T) or OUTREACH (F)**
@DesignProRenew	DesignPro Renewables	Developing a range of **hydrokinetic** turbines that can harness clean, **renewable energy** from rivers and estuaries. Sister company to @DesignProLtd.	TRUE
@banksofmylee	BanksOfMyOwnLovelyLee	#CorkTidalBarrier badly needed. OPW Walls are destructive to heritage and wildlife, too time consuming, and a waste of public money. Independent Review needed	FALSE
@Our**Ocean**Wealth	Our **Ocean** Wealth IRL	@Our**Ocean**Wealth provides information and updates on Ireland's Integrated **Marine** Plan – Harnessing Our **Ocean** Wealth. Visit our**ocean**wealth.ie for details	TRUE
@LadyReverb	Lady Reverb	Artist, Writer, Activist, Leftist. Anti-Capitalist Bernie2020. RTs ≠ endorsement. No lists. No 's. #IWW#DSA #MniWiconi #BlackLivesMatterMAHAFia	FALSE

Bolded words indicated words or phrases that triggered the algorithm.

TABLE 5 | Summary statistics of variables used in the regression analyses.

Summary statistics			
Variable	**Mean**	**Median**	**Standard deviation**
Retweets	3.71	2.00	4.52
Reach	0.40	0.00	0.49
Photos	0.37	0.00	0.74
Hashtags	1.03	1.00	1.38
Mentions	2.06	1.00	2.09
Links	0.49	0.00	0.53
Sentiment	1.58	0.00	2.88

TABLE 6 | Summary statistics based on the dichotomous dependent variable REACH used to understand tweet engagement by MaREI's outgroup users.

Summary statistics for REACH						
	REACH					
	Ingroup, Reach = 0			**Outgroup, Reach = 1**		
Variable	**Mean**	**Median**	**Standard deviation**	**Mean**	**Median**	**Standard deviation**
Retweet	1.76	1.00	2.27	6.76	5.00	5.43
Photos	0.24	0.00	0.68	0.56	0.00	0.80
Hashtags	1.11	1.00	1.48	0.90	0.50	1.19
Mentions	1.89	1.00	1.95	2.32	2.00	2.28
Links	0.45	0.00	0.52	0.55	1.00	0.54
Sentiment	1.21	0.00	2.44	2.15	1.00	3.39

Descriptive Statistics

Table 5 shows the descriptive statistics for the variables used in the regression analyses. MaREI's mean retweet frequency per OL post from January 2017 to September 2018 was 3.71. Outgroup members engaged with less than half (40%) of the analyzed tweets, demonstrating that a majority of MaREI's Twitter engagement with OL themed posts came from like-minded users. The typical OL tweet was comprised of 1.03 hashtags, 2.06 mentions, and used predominantly positive language demonstrated by a mean sentiment score of 1.58. A mean number of 0.37 photos and 0.49 links were posted across all 257 tweets analyzed.

Table 6 presents the summary statistics for OL tweets as related to the dependent variable REACH. The results show substantial variation in post characteristics for tweets that were retweeted by outreach users, versus tweets that were not. Overall, OL posts that were retweeted by outreach users were retweeted on average 6.76 times, while posts retweeted by only inreach users were retweeted 1.76 times. We found the average numbers of photos, mentions, links, and sentiment to be higher for posts that were retweeted by outgroup users. Hashtags were the only characteristic that did not exhibit this relationship; posts with more hashtags were, on average, retweeted less frequently by outreach users.

Regressions Results

Tables 7, **8** present the results of the regression analyses. **Table 7** displays the results of the NB regression for RETWEETS, while **Table 8** displays the results of the MLR for REACH. The estimated coefficients for variables, β_j, are presented alongside their *z*-value. *Z*-values were used to calculate corresponding *p*-values, highlighting the relational significance of a predictor variable to the outcome variable within statistically appropriate confidence intervals. The validity of each model is presented under Diagnostics.

Negative Binomial

All variables used to estimate $E(R_n)$ were significant at or above the 10% level. Coefficients for Photos ($\beta = 0.50$) and Mentions ($\beta = 0.15$) were positive and statistically significant at $p < 0.01$. Links ($\beta = 0.30$) and Sentiment ($\beta = 0.04$) also demonstrated a positive relationship with RETWEET frequency, with significance levels of $p < 0.05$ and $p < 0.1$, respectively. The only negative coefficient estimated by the model was for Hashtags ($\beta = -0.13$, $p < 0.05$).

The estimated coefficients allude to the magnitude of each independent variable's effect on the model's outcome variable. Interpreting this relationship first requires an exponential transformation of the coefficients, $\exp(\beta_i)$, given the log link function used in the negative binomial model (Eq. 2). The $\exp(\beta_i)$ value demonstrates the relative percent increase in RETWEETS

TABLE 7 | Predictor variables presented alongside their *z*-values and standard errors (*SE*).

NB regression results for RETWEET			
Variable	**β (*z*-value)**	***SE***	**Exp(β_i)**
Constant	0.602 (4.57)***	0.13	
Photos	0.50 (6.23)***	0.08	1.65
Hashtags	−0.13 (−2.53)**	0.05	0.88
Mentions	0.15 (5.15)***	0.03	1.16
Links	0.30 (2.45)**	0.12	1.35
Sentiment	0.04 (1.784)*	0.02	1.04
Diagnostics			
α	2.94***		
N	255		
Log-likelihood	−589.185		
Standard error	0.20		
Chi-squared	69.92***		

*The dispersion parameter, α, was found to be significant, validating the use of a NB model. Significant p-values represented as: ***p < 0.01, **p < 0.05, *p < 0.10.*

TABLE 8 | Logistic regression results for the dichotomous outcome variable REACH.

Logistic regression results for REACH			
Variable	**β_j (*z*-value)**	***SE***	**Odds ratios (95% CI)**
Intercept	−0.97 (−3.47)***	0.28	
Photos	0.58 (2.74)***	0.21	1.82 (1.24, 2.66)
Hashtags	−0.18 (1.73)*	0.11	0.89 (0.73, 1.08)
Mentions	0.11 (−1.65)*	0.06	1.10 (0.98, 1.24)
Links	0.20 (0.73)	0.27	1.43 (0.89, 2.3)
Sentiment	0.10 (1.99)**	0.05	1.12 (1.02, 1.23)
Diagnostics			
N	255		
Null Deviance	342.54		
Log-likelihood	−160.22		
Chi-squared	22.10***		
Hosmer–Lemeshow (GOF)	4.13		

*Significant p-values represented as: ***p < 0.01, **p < 0.05, *p < 0.10. The Hosmer–Lemeshow goodness-of-fit (GOF) test was used to assess the fitted model's overall departure from the observed data, where test metrics with low p-values suggest rejection of the model (Lemeshow and Hosmer, 1982; Archer and Lemeshow, 2006). The metric was not statistically significant (p-value = 0.845), suggesting that the model adequately fits the data.*

for every incremental increase in the corresponding variable, holding all other variables constant. For example, a one-unit increase in the number of photos included in a tweet is expected to increase RETWEETS by 65%. We found that a one-unit increase for each predictor variable is expected to increase RETWEETS, except, for Hashtags.

Multivariate Logistic Regression

The results of the logistic regression identify predictor variables that significantly influenced the likelihood of a tweet being retweeted by an outreach user. Photos (β = 0.58, $p < 0.01$), Sentiment (β = 0.10, $p < 0.05$) and Mentions (β = 0.11, $p < 0.1$) were found to positively influence the likelihood of a post being retweeted by an outreach user. Our model estimated no statistical influence from the number of Links present in a post (β = 0.20, $p > 0.1$). We found that an increase in the number of Hashtags ($\beta = -0.18$, $p > 0.1$) decreased the likelihood of an outreach user retweeting an OL post.

Table 8 also displays the odds ratios for each predictor, and were calculated by exponentiation estimates of β_j. In this instance, odds ratios represent how the odds of a post being retweeted by an outreach user change for every incremental increase in a given variable, holding all other variables constant. Odds ratios greater than 1 describe positive relationships, while odds ratios less than 1 demonstrate negative relationships. Meaningful interpretations of odds ratios require corresponding 95% confidence intervals to be fully above or below one (Peng et al., 2002; O'Brien and Dunson, 2004). Therefore, only variables found significant at $p < 0.05$ – Photos and Sentiment – can be used to confidently explain changes in the odds of a post being retweeted by an outreach user.

The odds ratios calculated by the logistic regression model show that for every incremental increase in the number of photos added to a post, the probability of an outgroup user retweeting a post from MaREI increased by approximately 82%. The Sentiment predictor mirrored this positive relationship. For every incremental increase in the positivity polarity of sentiment added to a post, the probability of an outgroup user retweeting a post from MaREI increased by 12%.

DISCUSSION

Online social media platforms like Twitter have redefined communicative infrastructure. Over 500 million tweets are sent every day (Newman, 2017), resulting in a prodigious exchange of data between users at any given time. Twitter is now a primary communication tool for businesses, news outlets, celebrities, and heads of state. Despite Twitter's growing societal influence, academia has been slow to integrate this novel communication technology. Initial reluctance stems from many scientists' views that Twitter is 'a waste of time,' provides no professional benefits, and may in fact harm one's scholarly reputation (Collins et al., 2016). However, recent surveys show that more and more academics are joining Twitter to engage with diverse audiences (Collins et al., 2016). It is therefore necessary for those in academia to understand how to utilize the features of Twitter to communicate science to non-scientific audiences, thereby harnessing Twitter's capacity as a tool for science outreach.

Our analysis of MaREI's Twitter audience, or the users that engagement with MaREI's tweets, found that 65% of MaREI's OL post retweeters were INREACH users, while the remaining 35% of retweeters were OUTREACH users. These findings reflect those of Côté and Darling (2018a), who found that, on average, 60% of scientists' followers on Twitter were other scientists, while the remaining 40% were non-academic scientists. Our results indicate that MaREI's Twitter account has the capacity to reach beyond the 'ivory tower,' but the center's OL posts may be subject to a degree of network homophily, where posts predominantly reach audiences that may already be highly ocean literate. For OL posts, retweet frequency with the outreach audience was indeed less than half (40%) of overall retweets. This reiterates the finding that a majority of MaREI OL posts predominantly reached the center's peers, and thereby remained in the 'ivory tower' with audiences that were considered to be already familiar with the subject matter.

RETWEETs

The literature substantiates that the characteristics of retweeted posts are significantly different than posts that are not retweeted (Suh et al., 2010). Our RETWEET results support these studies, revealing similar trends in the relative influence of post characteristics on users' retweet behavior, while also highlighting an irregular negative influence from Hashtags on retweet frequency. By applying a zero-truncated NB model, we found Photos [$\exp(\beta) = 1.65$, $p < 0.01$], Mentions [$\exp(\beta) = 1.16$, $p < 0.01$], Links [$\exp(\beta) = 1.35$ $p < 0.05$], and Sentiment [$\exp(\beta) = 1.04$, $p < 0.10$] to be significantly and positively correlated with the number of times a post was retweeted. A similar study by Wadhwa et al. (2017) analyzed the Twitter account of the *American Journal of Neuroradiology* (@TheAJNR) and found that the use of a photo was the most influence tweet characteristic in increasing user engagement (58.02% higher engagement rate than posts without photos). Interestingly, very few studies have examined the correlation between the number of photos in a tweet and the frequency it is retweeted. To our knowledge, this study is the first to demonstrate that an incremental increase in the number of photos used in a post increases the probability of that post being retweeted. As Twitter permits a maximum number of four photos per post, the results strongly suggest that using this feature to the allowed maximum number for a post is worthwhile. The authors, however, would admit that if there were no limit, we would not expect this relationship to continue, and that the quality and type of images posted most likely influences retweet behavior, as demonstrated on other social media platforms like Instagram (Hu et al., 2014).

A number of studies have focused on how the use of Mentions, Links (sometimes measured as URLs), and Sentiment affect retweets. For example, Suh et al. (2010) conducted an extensive exploratory analysis of 10,000 random tweets to understand features associated with posts' "retweetability." Using logistic regression analysis, the study found higher retweet probabilities for tweets containing URLs ($\beta = 0.73$, $p < 0.01$) and Hashtags ($\beta = 1.33$, $p < 0.01$), yet a marginally lower retweet probability for tweets containing Mentions ($\beta = -0.29$, $p < 0.10$). Our results show a similar positive relationship with URLs (Links), however, we identified the opposite relationship between retweets, and Hashtags and Mentions. This may be a result of our non-random collation of tweets, having focused on a single Twitter account (@MaREIcentre), as well as a specific type of tweet (OL themed posts). However, Suh et al. (2010) note that, "not all popular hashtags in tweets are popular in retweets," suggesting that the type of hashtag used matters for a tweet's retweetability. This provides interesting context regarding the negative correlation for Hashtags found in our study. Hashtags are used to facilitate the categorization of posts and effectively group tweets with similar content. Therefore, posts with certain hashtags may be subject to in-group favoritism, causing certain users disengage if too many hashtags are included that are perceived as unfamiliar. Science based accounts need to be aware of the hashtags they are using, making sure not to alienate large populations with technical jargon.

Our results also demonstrate that positive sentiment, or positive emotional valence, has a significant positive influence on retweet probability. The integer scale of the SA used in this study allowed us to not only test the influence of overall sentiment, but the polarity of a tweet as well, i.e., the positivity or negativity of a tweet's language. We found a moderately significant positive relationship ($\beta = 0.04$, $p < 0.10$) between a post's sentiment score and its retweet frequency, indicating that users were more likely to retweet OL posts if they used positive language as opposed to negative language. Stieglitz and Dang-Xuan (2013) found similar relationships concerning emotions and political information diffusion on Twitter. The study analyzed a set of tweets regarding German state parliament elections in 2011, and found a positive correlation between the amount of sentiment (positive or negative) in political Twitter messages and the frequency and speed at which a post was retweeted. Interestingly, the study found no support for the notion of negativity bias (Baumeister et al., 2001; Rozin and Royzman, 2001), regarding retweet quantity and retweet speed, stating that posts with negative content were not retweeted more frequently or more quickly than posts with positive content. Negativity bias has been shown to be particularly strong in the domain of news. Yet, outside of that domain, findings from other studies show that the opposite may hold true (Hansen et al., 2011). The integer scale of the SA used in this study allowed us to not only test the influence of overall sentiment, but the polarity of a tweet as well, i.e., positivity or negativity of its language. This allows us to extend similar claims refuting the notion of negativity bias, specifically for science based tweets. We extend our discussion of sentiment and science communication in the following section, specifically as to how it relates to our REACH variable.

REACH

In addition to analyzing users' overall retweet behavior, we analyzed the degree to which retweet behavior differed between users inside and outside of MaREI's immediate network. This provided a means to investigate how post characteristics influenced MaREI's ability to use Twitter as a medium for ocean literacy outreach. We found post characteristics differed substantially for retweets by outreach audiences versus those retweeted by the inreach group. The average number of photos, mentions, links, and positive sentiment was higher for retweets by the outreach audience. In addition, the OL posts retweeted by outreach audience members gained more momentum within the wider Twitter network, with an average retweet rate of 6.76 times; the average retweet rate resulting from inreach interaction was only 1.76 times. This suggests not only that the center can indeed tweet with purpose to reach outreach audiences by adjusting future OL post characteristics accordingly, but that if OL posts initially reach the intended audiences, the posts have a greater chance to spread to wider audiences. The analyses revealed that the inclusion of photos and positive sentiment significantly increased the probability that outreach audiences would retweet a post.

Using logistic regression analysis, we found Photos and Sentiment significantly increased the probability of an OL themed post being retweeted by an OUTREACH user. Photos increased the probability of a retweet from an outreach user by 82% ($p < 0.01$) for every additional photo added to a post, holding all other variables constant. This finding supports the current literature on the positive relationship between the presence of a photo and retweet frequency (Wadhwa et al., 2017, 2018), however, sheds new light on the ability of photos to increase Twitter engagement with outreach users.

A similar positive relationship was found for the inclusion of positive sentiment, independently increasing the probability of a retweet by 12% ($p < 0.05$) for every incremental unit increase. As discussed above, our results support the findings of a number of previous studies (Bravo-Marquez et al., 2013; Stieglitz and Dang-Xuan, 2013; Hales et al., 2014; Ferrara and Yang, 2015a,b; Brady et al., 2017; Garimella and Weber, 2017), demonstrating that emotions play a key role in retweet behavior. In addition, this study presents novel insight into how positive language can increase the probability of a tweet being retweeted by outreach users, extending the knowledge base related to the use of SNSs as a tool for science communication, public engagement, and outreach.

Given the increasing influence of social media as a vector for information diffusion, our analyses have far reaching implications for improving the public's engagement with environmental issues, such as marine pollution and climate change. Most notably, our results demonstrate that Twitter posts using positive language are more likely to be retweeted, as well as more likely to be retweeted by outreach users. Our findings support multiple studies concerning pro-environmental behavior, indicating that people are more likely to respond to positive language than negative language. Media representations of environmental issues like climate change are overwhelmingly discussed using fear appeals and alarmism (O'Neill and Nicholson-Cole, 2009), often communicated in the context of punctuated dramatic events. As discussed above, several studies have found that using negative sentiment, such as fear appeals and apocalyptic dialog, is unlikely to influence environmental behavior long-term (Lowe et al., 2006). Rather, individuals are more likely to respond with increasing dissonance, rationalizing such issues as impersonal and distant in both time and space (O'Neill and Nicholson-Cole, 2009). Furthermore, Hastings et al. (2004) found that excessive fear appeals may be suspect to a law of diminishing returns, sometimes referred to as apocalypse fatigue (Nordhaus and Shellenberger, 2009), where individuals become desensitized to the severity of an issue.

CONCLUSION

The integration of Twitter in academia is beneficial for scientists' careers (Eysenbach, 2011), and provides a unique platform for two-way interactions between researchers and the general public (Smith, 2015; Ke et al., 2017). Scientists that harness the networking power of Twitter have the potential to proliferate science literacy with a unique degree of accessibility. However, to our knowledge, no studies have looked to understand how the attributes of science-based tweets influence scientists' ability to engage with diverse audiences. This study provides a foundation for understanding how to facilitate effective communication between academia and the general public on Twitter. By looking only at posts related to Ocean Literacy, our results capture the general public's behavioral responses on social media to science-based tweets. Using the MaREI Twitter account as a case study, we demonstrate that the inclusion of photos and positive sentiment independently increase the likelihood of engaging with an outreach user by 82 and 12%, respectively. These results imply that simply tweeting scientific information does not necessarily constitute effective communication, and that the attributes of a post significantly impact scientists' ability to engage with individuals outside of their immediate network.

As discussed, our results have several implications concerning the use of Twitter for ocean literacy, science communication, and academia's overall engagement with different user types on social media. Previous studies have looked to classifying types of users on twitter, and have looked to identifying what types of posts users interact with. However, no studies, to our knowledge, have combined these approaches to understand how different Twitter user types respond to different types of posts on twitter, particularly concerning posts with science based content. This is especially important for academic users on twitter that want to engage with wider audiences.

Furthermore, the authors cannot overstate the significance of this study's results relating to the importance of using photos and positive sentiment in communicating science with the intention of engaging outreach users. Scientific literacy is a necessary component of a just, functional, and democratic society (Lehr, 2007), yet, historically, science communication avenues have been relatively inaccessible – often confined to the upper echelons of academia. For these reasons, the importance of studies that focus on improving science communication, such as ours, transcends disciplines, maintaining the notion that informed citizens 'make democracy work (Milner, 2002).' The mass communicative integration of SNSs like Twitter provides a fast, easy, and widely accessible platform for academics to engage with members of the public. Many researchers advocate for the use of Twitter in academic environments, especially as a means for science communication (Kassens-Noor, 2012; Shiffman, 2012; Mckay et al., 2014; López-Goñi and Sánchez-Angulo, 2017), yet there are few examples of its use in the literature, and little to no peer-reviewed information on how to improve science outreach on Twitter. Here, we present novel information regarding the ways science outreach on Twitter can be improved through the use of photos and positive language.

As environmental issues continue to move to the forefront of societal discourse, scientists, now more than ever, must communicate their research in ways that produce palpable change. This study provides the first analysis of scientists' ability to communicate ocean literacy themes to different user types on Twitter. Further research is needed to better understand how, or if, interactions on Twitter correspond to behavioral changes in real life. For example, what evidence is there to suggest that interactions on Twitter concerning environmental issues, such as marine litter, actually increase pro-environmental behaviors in real life? This should be further supplemented by examining the effectiveness of different SNSs, e.g., Twitter vs. Facebook, in disseminating scientific information to different audiences. Lastly, our results concerning hashtags and outreach user engagement do not support previous findings, and merit further investigation, specifically regarding the ways in which the use of Hashtags may facilitate in-group favoritism and homophily.

Limitations

While the authors attempted to optimize this study's methodology, there are nevertheless limitations worth recognizing. Firstly, the study's focus on a single user's profile (@MaREIcentre), along with a single topic (ocean literacy) may limit the generalizability of our results. We highly recommend further research be done to improve the overall understanding of how science-based Twitter accounts engage with members of the wider public.

Secondly, our binary INREACH–OUTREACH classification system relied solely on information available in users' bio, handle, and username. While we addressed these issues as best we could, misclassification remained an issue. Therefore, we highly recommend future research employ machine learning techniques to more accurately identify scientists on twitter. Such methods incorporate latent user attributes – including post behavior – that would likely improve the accuracy of user classification, and provide further insight into how certain user groups interact with one another on Twitter.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this manuscript will be made available by the authors, without undue reservation, to any qualified researcher.

AUTHOR CONTRIBUTIONS

KK, JB, and AD conceived and explored the idea together. KK led work on literature review and discussion and conclusion. JB led work on methods and results, and contributed significantly to discussion and conclusions. AD contributed to all aspects of the paper and designed both figures.

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Feasible Options for Behavior Change Toward More Effective Ocean Literacy: A Systematic Review

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Effective ocean literacy requires appropriate individual behavior, but achieving this—based on behavior change—is extremely difficult. Social-psychological research shows that even generating knowledge and awareness toward protecting the environment—including the oceans—very rarely produces behavior change. The correlation between knowledge and behavior change is demonstrably surprisingly low. Based upon a systematic interdisciplinary literature review, this article evaluates the factors constituting behavior that are important for ocean literacy. Furthermore, it includes an analysis of options for individual behavior change. The literature review covers research and theories from behavioral sciences such as social, environmental, and emotional psychology, as well as from other social sciences. Specifically, research on pro-environmental behavior is evaluated and applied to the specific case of ocean-related behaviors and ocean literacy. As a result, the model of pro-environmental behavior by Kollmuss and Agyeman has successfully been transferred to increase the effectiveness of ocean literacy because it considers internal (e.g., emotions and values) and external factors (e.g., politico-economic and socio-cultural), which are crucial to achieve behavior change. Further results show that the theoretical analysis of different influence factors of ocean related behavior help to identify options to enhance ocean literacy, partially not yet broadly applied in this field, such as reputation-based incentives, social marketing, and successfully diffusing social change, which is illustrated within two examples of success stories. Nevertheless, improvements remain challenging due to barriers identified on the individual level (e.g., cognitive dissonance and moral disengagement) and adverse political and economic power relations in light of rapidly increasing environmental problems in our oceans.

Keywords: ocean literacy, individual responsibility, sustainable behavior, behavior change, social norms, cognitive dissonance, moral disengagement, model of pro-environmental behavior

INTRODUCTION

Ocean environments are under exceptional pressure by anthropogenic activities leading to climate change, marine pollution, and overexploitation of fish stocks, with their severe negative impacts for marine ecosystems and humans—particularly in densely populated coastal regions (Lubchenco et al., 2016). The generally worse state of the oceans, with no area unaffected by human influence and a large fraction (41%) strongly affected by multiple drivers, requires urgent, comprehensive, and efficient actions to save the oceans and prevent even more mis- and overuse (Halpern et al., 2008; Gattuso et al., 2018). Also, all kinds of land-based activities, such as related to tourism and urban growth, cause habitat destruction and overexploitation. More specifically, pollutants from households and industry and nutrients from agriculture lead to problems such as contamination and eutrophication (Billé et al., 2013; WBGU, 2013; EEA, 2015). Further sea-based problems, in addition to fishing and aquaculture, are noise pollution through ship traffic, renewable energy production, as well as oil and natural gas exploration (ibid).

Anthropogenic climate change is constantly becoming the biggest threat and has already led to increasing sea temperatures, ocean acidification, and additional changes like rising sea levels, increasing ocean stratification, decreasing sea-ice extent, altered patterns of ocean circulation, and modified oxygen content at the surface (Halpern et al., 2007; Doney et al., 2011; Borja et al., 2013; Gattuso et al., 2018; McCauley et al., 2019).

These complex interrelationships show the necessity of becoming "ocean literate," of course in addition to political action such as implementing the marine related Sustainable Development Goal 14 *"Conserve and sustainably use the oceans, seas and marine resources for sustainable development"* (United Nations, 2015). Ocean literacy is not only defined as the "understanding of the ocean's influence on you and your influence on the ocean" (Cava et al., 2005, p. 5, see also Santoro et al., 2017 for a comprehensive practical guide on ocean literacy; Fauville et al., 2018), but also as "being able to make informed and responsible decisions regarding the ocean and its resources" (Cava et al., 2005, p. 5). This second part of the definition is of particular importance because options and incentives for individual behavior change toward less harming and more protecting the oceans, their ecosystems, and related populations are urgently needed. A similar useful concept is ocean citizenship because it recognizes that individual behavior can impact coastal and marine spaces and therefore "reflects an individual's relationship with place—either in a direct sense through personal interaction (in this case with the ocean), or indirectly through resource use and lifestyle choice (in this case in relation to ocean resources)" (Fletcher and Potts, 2007, p. 521). In recent years, the concept of ocean citizenship has been expanded to include environmental behavior and requires massive behavioral changes at the individual level, e.g., related to consumer choice to reduce environmental impacts (McKinley and Fletcher, 2010; Jefferson et al., 2015; Santoro et al., 2017). However, both concepts—and this is important for this article—emphasize the role of individuals.

Responsibilities of individuals cannot be ignored: McKinley and Fletcher (2010) point out that "the degradation of the marine environment can be partially attributed to the collective day-to-day impact of the behavioral and lifestyle choices made by individuals" (p. 379). Conversely, individuals have the potential to substantially contribute toward sustainable futures on land and in the seas through exercising consumer choice, as well as reducing demands on fisheries and their own carbon footprint (Vincent, 2011; Jefferson et al., 2015). For example, individual lifestyle choices directly influence energy consumption, material consumptions, and consequent emissions, representing 45–55% of total energy use. The most important activities in this context are living car free; flying less; eating fewer animal-based products, in particular meat and cheese; using low-carbon transport; heating less and with green energy only; voting for "green" policies; and promoting and campaigning for a low-carbon future (Whitmarsh and O'Neill, 2011; Wynes and Kimberly, 2017). When it comes to oceans, one has to add activities such as living as plastic free as possible, eating no or only sustainably caught fish, and campaigning and engaging for ocean conservation.

The main research question of this article is *what the barriers, opportunities and incentives are to encourage more ocean friendly behavior*, based on an interdisciplinary and multifactor approach. In line with this, the article explores and summarizes the factors that shape ocean-relevant individual behavior, bearing in mind that it is often the common denominator underlying a necessary wider social movement to ensure the sustainable use of the ocean as a natural resource. This is particularly the case in situations in which responsibly designed environmental marine policies, regulations, and management strategies are lacking or implemented too slowly.

METHODS

Factors that influence ocean-related behavior were investigated on the basis of an interdisciplinary systematic literature review with an emphasis on behavioral sciences such as personality, emotional, social, and environmental psychology, but also from consumer and marketing research, sociological, educational, political and—of course—marine sciences. There are many such studies, but a synthesis and systematic analysis of them is lacking. According to Magliocca et al. (2015) it makes sense to "distill the findings of many narrowly focused analyses (i.e., "cases") to produce knowledge that is more generally applicable than may be derived from a single case" (p. 213). It was started by collecting together a bank of research studies based on an already existing constantly updated database of the author who does research on the issue of behavior change since a while. In addition, a type of snowball method was applied by tracking new references, in particular on ocean and marine related behavior but also on new studies on pro-environmental behavior in general. According to Greenhalgh and Peacock (2005), "in systematic reviews of complex and heterogeneous evidence [...] [as is the case for this paper] formal protocol-driven search strategies may fail to identify important evidence" (p. 1065). Based on an initial assessment of the literature and the studies found via the snowball methodology, keywords (such as ocean literacy, ocean governance, ocean citizenship, pro-environmental behavior, and sustainable consumption) were formulated to an additional search for literature on the ISI Web of Science and other search engines. The search returned publications were sorted according to the thematic fit of their titles and abstracts.

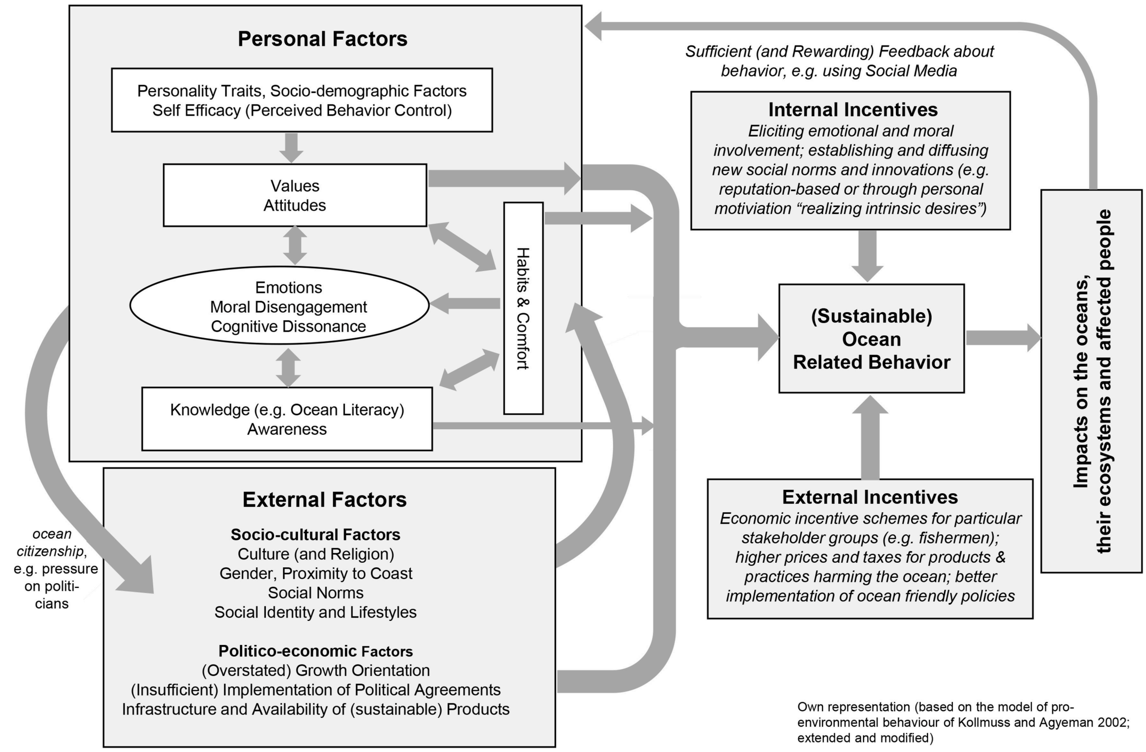

FIGURE 1 | Conceptual model of factors influencing ocean-related sustainable behavior.

The following criteria were met:

- The content had to relate to ocean related behavior in a wider sense (including environment and climate related) or at least to sustainable consumption behavior
- The results of the studies had to provide more or less generalizable evidence about factors
- Articles in peer-reviewed academic journals in English language in the time period of 2000–2019

In total, 102 papers were selected for the systematic literature review (see Electronic **Supplementary Material**).

The next step of the analysis was to code the selected studies. Code families included method (review, qualitative, quantitative), data background (empirical primary data, empirical secondary data, theoretical), thematic category (ocean-related and sustainable consumption and pro-environmental (including climate related) behavior, and the context of factors that influence ocean related behavior (see below) with further sub-codes. The latter codes were generated from the model described below and previous peer-reviewed research (Stoll-Kleemann and Schmidt, 2017) and adapted to the particular issue of ocean related pro-environmental behavior (see **Figure 1**).

After analysis and structuring of the relevant research results from these articles the model of pro-environmental behavior developed by Kollmuss and Agyeman (2002) has been adopted and further factors have been incorporated. This decision has been supported by a review of a large number of theoretical frameworks on individual behavior based on Darnton's (2008) comprehensive overview of behavior-change models. The rationale of selecting and using this model for explaining (sustainable) ocean-related behavior lies mainly in its extensive breadth and its multifactor approach. According to Gifford and Nilsson (2014), many studies have shown that well-known established social-psychological models such as the theory of planned behavior (Ajzen, 1991), the value-belief-norm model (Stern, 2000), and the norm-activation theory (Schwartz, 1977) should be "expanded to include other personal and social factors" (Gifford and Nilsson, 2014, p. 141). Therefore, the model developed here is divided into two levels, namely personal (internal) and external factors (such as factors related to social norms, culture and religion, infrastructure and availability of sustainable products and politico-economic factors).

The emphasis in this article is on the multiple personal influence factors such as a person's personality traits and demographic factors as well as self-efficacy (perceived behavioral control). Knowledge, values and attitudes as factors are highly dependent on the information-processing system guided by emotions and the desire for comfort and a certain lifestyle. These are included in the model as they are core factors of behavior. In particular, habits and comfort are justified on the basis of processes such as cognitive dissonance and moral disengagement. They are at the center of the model because they help to understand personal reluctance to follow ocean-friendly practices. The interrelations among these groups of factors are also explicitly incorporated into the model, which increases its complexity, but also its explanatory power. This article has its focus on individual behavior; politico-economic factors are addressed, but in less detail compared to the discussion of personal factors. The arrows in the model indicate how the different factors influence each other and, ultimately, the probability of ocean-friendly behavior. On the right side of the box, a distinction is made between different incentives, more internal (e.g., establishing and diffusing more ocean-friendly social norms) on the one hand, and external, e.g., economic incentives on the other. These incentive structures should be supported by sufficient (or, if appropriate, even rewarding) feedback in regard to those behaviors leading to less harm for or protection of the oceans.

RESULTS

Quantitative Assessment

Quantitative Assessment of Studies of the Systematic Review

The majority of the 102 articles reviewed ($n = 52$) employs a quantitative research approach, reflecting the representativeness of many results. Review articles ($n = 39$) indicate the general applicability of theories and evidence. Due to the importance of both personal and external factors in influencing (ocean-related) pro-environmental behavior, qualitative studies ($n = 11$) help to clarify complex behavior patterns (**Figure 2A**). The majority ($n = 90$) of the studies presents empirical data, of which the vast majority is primary data ($n = 55$). Twelve articles are theoretical essays and were included both to reflect current discussions and to explain theoretical models (**Figure 2B**). Some 24 of the 102 of the works cover aspects of purely ocean-related behavior. The remaining 78 focus on other sustainable consumption behaviors, mainly pro-environmental and/or climate related more generally (**Figure 2C**). **Figure 2D** shows the mean number of factors addressed per study (5.46 for ocean-related behavior and 6.09 for general pro-environmental behavior). This indicates that behavior is indeed multi-dimensional. Ocean-related behavior studies address nearly the same number of factors as more general ones, showing the relevance of synthesis.

In **Figure 2E**, it is evident that multiple factors are seen as important, but that there are several differences between ocean-related studies and the more general works on pro-environmental behavior. "Values & Attitudes" is the most-often-named factor (79 studies overall) and nearly equally important in both types of studies. The second most-cited factor is related to "Economic/Political Aspects" ($n = 63$) and shows big differences between study types: in ocean-related works, this factor is described in 83.3% ($n = 20$) of all articles, but only in 55.1% ($n = 0$ 43) in the more general studies on pro-environmental behavior. A similar picture arises for the third-most-often named factor, "Social Norms" ($n = 61$): 66.7% ($n = 52$) of the general studies regard this factor as influencing behavior, but only 37.5,% (n9) of the ocean-related studies describe this factor as relevant. The difference is even bigger for the factor "knowledge" ($n = 58$), with only 48.8% ($n = 38$) of the general studies mentioning it as a factor; in contrast 83.3% ($n = 20$) in the ocean-related articles cite it. Even where knowledge is expressly highlighted in the more general pro-environmental behavior studies, it is often framed as overestimated (see below, qualitative assessment).

Similarly, strong differences appear for the less-frequently-named factors "Social Identity & Lifestyles" ($n = 45$); "Self-Efficacy/Perceived Behavior Control" ($n = 35$); "Habits & Comfort" ($n = 33$); and "Culture & Religion" ($n = 31$), with the first three mentioned much more often in the general studies: "Social Identity & Lifestyles" 52.6 vs. 16.7%; "Self-Efficacy/Perceived Behavior Control" 41 vs. 12.5%; and "Habits & Comfort" 41 vs. 4.2%). In contrast, "Culture & Religion" is strongly emphasized as an important factor in ocean-related studies (50 vs. 24.4%). These differences mirror the fact that the majority of the general studies stems from the behavioral sciences. Nontheless, they clearly indicate that it would be worthwhile for studies on ocean-related behavior to consider reflecting on incorporating these kinds of factors as well. The factor "Emotions & Cognitive Dissonance" is examined in 51 (39 + 12) of the reviewed studies and equally often (50%) in both types. Similarly, the factor "Personality Traits / Socio-demographic..." ($n = 42$, i.e., 32 + 10) is also named equally often in both types (41%). The external factor relating to "Sustainable Infrastructure & Products" is named in 44 studies.

Overall, this quantitative assessment might suggest the importance of a variety of factors, but it may also provide insight into those that researchers view as important to examine with regard to pro-environmental and/or ocean-related behavior. Most of the studies ($n = 81$) were published between 2010 and 2019, highlighting the emerging research field (see Electronic **Supplementary Material**).

Qualitative Assessment: Factors That Influence Ocean Related Behavior

Personal Factors

Increasing *knowledge and awareness* concerning ocean environments are at the heart of ocean literacy and often assumed as preconditions (or even a guarantee) for achieving sustainable ocean-related behavior. Professionals dealing with ocean literacy want individuals—at least—to "demand an understanding of ocean processes and the inter-connectivity of the land and sea" and—at best—to understand more contested and complex notions related to "sustainability, equity and democracy" (Fletcher and Potts, 2007). Results from several articles show that, in general, people who live in coastal areas are more aware of relevant ocean issues, but that the baseline awareness of the oceans is very low (see e.g., Steel et al., 2005; Fletcher and Potts, 2007; Potts et al., 2016; Fauville et al., 2018). In an empirical study focusing on Ireland, McCauley et al. (2019) found out that there is a lack of knowledge of important actors such as policy makers, teachers, and lecturers and, moreover, a lack of understanding of the importance of the ocean in our cultural, social, and environmental heritage, which makes it more difficult to deal with the issue at hand.

Nevertheless, even though living close to the coast generally leads to better knowledge of the oceans, it does not necessarily lead to changed behavior. There is no evidence that more knowledge, education, and public awareness of the oceans directly leads to sustainable behavior. Fletcher

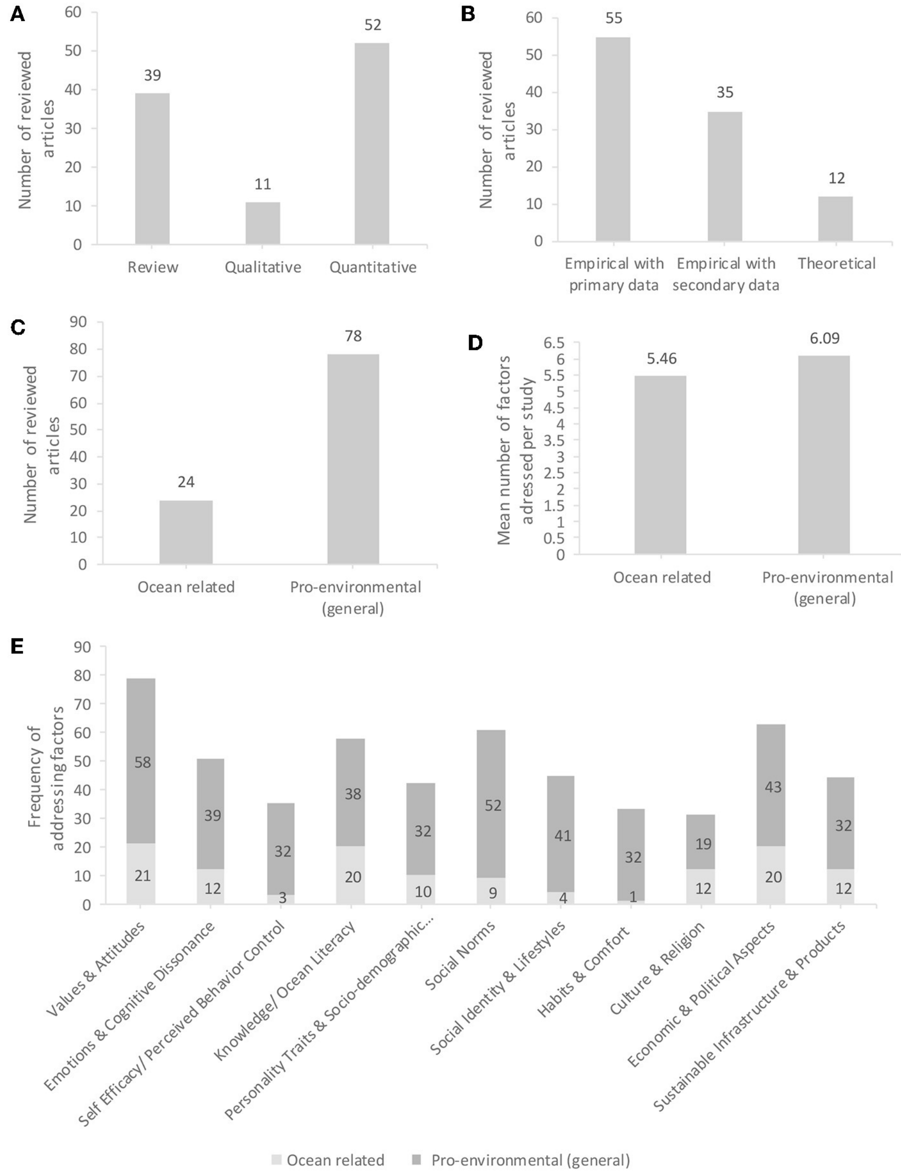

FIGURE 2 | (A) Total number of articles reviewed according to their approach. **(B)** Total number of articles reviewed according to their data background. **(C)** Number of studies reviewed according to the category of behavior addressed. **(D)** Mean number of factors addressed per reviewed study. **(E)** Frequency of cited factors regarded as most influencing patterns of ocean related and general pro-environmental behavior, additionally divided according to the category of behavior addressed in the respective study (one article can consider more than one category; left: personal factors, right: socio-cultural and other external factors). See text for full explanation.

and Potts (2007) express the opinion that replacement of the common "surface learning" with "deep learning" would be helpful. "With deep learning, individuals understand the complexities and interconnections involved with the issue, including cause and effect. This implies that in order to exercise ocean citizenship, individuals must not only be aware of ocean issues, but understand how their behavior can affect, either positively or negatively, the oceans" (p. 513).

Unfortunately, although deep learning is certainly much more effective than surface learning in numerous respects, Fletcher's and Potts's opinion has not been confirmed by established research demonstrating that "only a small fraction of pro-environmental behavior can be directly linked to environmental knowledge and environmental awareness" (Kollmuss and Agyeman, 2002, p. 250). The gap between knowledge/awareness and behavior—which can be found in all areas of life—is explained by the fact that "at least 80% of the motives for pro-environmental or non-environmental behavior seem to be situational factors and other internal factors" (Barr et al., 2011; see also Barreto et al., 2014; ibid). In concrete terms, this means that although concern is expressed about ocean sustainability (see e.g., Gelcich et al., 2014; Potts et al., 2016), people ultimately give it a low priority in their lives within the context of everyday issues. Albert Bandura—one of the most influential psychologists and whose theory of selective moral disengagement is presented as an important explanation below—puts it like this: "Bountiful immediate rewards of consumptive lifestyles can easily override distant adverse effects, especially if slowly cumulative" (Bandura, 2007)—as it is the case with actions that harm our oceans.

In general, the mis- and overuse of the oceans pose significant challenges to our perceptual, cognitive, and affective information-processing system—similar to climate change—making it and its threats difficult to engage with. The more abstract, dissimilar, and socially distant the impacts and ostensibly "real victims" seem to be—be they ecosystems including animals, members of faraway communities or, perhaps, future generations—the less morally obligated people will feel to act on their behalf (Markowitz and Shariff, 2012).

Another problem is the "blamelessness of unintentional action": no one wants to pollute the oceans or is purposefully trying to make it happen. Although the problems of our oceans are the direct result of intentional, goal-directed behavior, they are perceived by many individuals as unintentional, if unfortunate, side effects of such actions. These types of "unintentionally caused harms" are assessed less harshly than "equally severe but intentionally caused ones" (Markowitz and Shariff, 2012, p. 244).

What are the "other internal factors" mentioned above that determine our behavior if not knowledge and awareness? The principles underlying human behavior appear simple: namely, "to seek out and attain rewards and to avoid punishments or penalties" (Blaukopf and DiGirolamo, 2007, p. 626). However, it becomes clear that the process is more complex than the assumption of differentiating rewards: The internal factors include basic needs for survival and reproduction (primary rewards), but can be more abstract and cognitive in nature (secondary rewards). Positive cultural values that must be learned, such as thinking monetarily, acclaim, security, knowledge, and praise are also associated. Of course, rewards that produce feelings of pleasure and liking reinforce the behavior that achieves them (ibid, p. 627). The anticipation of rewards leads to motivated behavior that can also be labeled goal-directed behavior (ibid, p. 632). The three main motivations for behavior include (I) hedonic ones, which lead individuals to seek ways to improve how they feel; (II) those that sensitize individuals to gains or losses in changes in their financial or other resources; and (III) normative ones, which are concerned with the correctness of their behavior (Lindenberg and Steg, 2007; Howes and Gifford, 2009; Steg et al., 2014).

Values are important to consider for achieving effective ocean literacy because they are the "guiding principles" that individuals use to judge situations: a person's sense of right and wrong or what "ought" to be" (Darnton and Evans, 2013, p. 7). One value-related question is the degree to which individuals admit their personal responsibility for ocean sustainability, which should ideally embrace both individual and collective action. Because "behaviors of individual actors at the local scale influence interactions at the regional or global scale", and "the collective effect of individual behaviors influences the larger-scale properties such that actors adapt to the changing conditions of the system context" (Lubchenco et al., 2016, p. 14508; see also Ostrom, 2009), it becomes evident that the emphasis on the aggregative nature of the various types of ocean-related harm follows the principle that "even if an act harms no one, this act may be wrong because it is one of a set of acts that together harm other people" (Parfit, 1987 and Peeters et al., 2015, p. 76).

In general, values are more abstract concepts than norms and attitudes, which usually refer to specific actions, objects and situation. In addition, "people's values form an ordered systems of value priorities that characterize them as individuals" (Schwartz, 2006, 1). In the Schwartz Value Survey opposing values are benevolence ("preserving and enhancing the welfare of those with whom one is in frequent personal contact") with achievement ("personal success through demonstrating competence according to social standards") and universalism ("protection for the welfare of all people and for nature") with power ("social status and prestige, control or dominance over people and resources") (Schwartz, 2006, 11). Related to these general values Clayton (2018) found that political orientation is determining attitudes toward environmental policy with an overall dislike of environmental policies being characteristic of conservatives.

In line with this, values have also been considered in terms of orientations toward self and others (Messick and Mc Clintock, 1968). Individuals with cooperative (pro-social) orientations emphasize joint gains between self and other, whereas those with competitive and individualistic orientations (pro-self) emphasize gains to themselves (Lindenberg and Steg, 2007; Kaiser and Byrka, 2010; Howell, 2013; Steg et al., 2014; Reese and Jacob, 2015). Individuals who are more people oriented and less authoritarian (Schultz and Stone, 1994); have higher levels of moral development (Swearingen, 1990); and believe their actions will make a difference tend to be more environmentally concerned (Howell, 2013; Antonetti and Maklan, 2014).

Unfortunately, relations between values and environmental (also ocean-related) views may not be simple because people have multiple values—and these can conflict (see above and Stern, 2000; Lindenberg and Steg, 2007; Howes and Gifford, 2009; Howell, 2013). For example, the presence of other people at events where choices are made about behavior that affects the oceans can have a powerful effect on behavior. This component of social norms, which is related to perceptions of normative behavior by socially connected peers, can be a barrier as well as an opportunity because people adjust their behavior "to manage their public image and create a certain impression on others" (Higgs, 2015, p. 39, see also Griskevicius et al., 2010; Farrow et al., 2017). Social norms may be communicated directly via cultural practices in a given situation (Higgs, 2015; Farrow et al., 2017; more on cultural issues below).

In addition, *personality traits*—the best established are the "Big Five: openness to experience, conscientiousness, extraversion, agreeableness, and neuroticism" (McCrae and Costa, 1999)—influence environmental behavior. Kaiser and Byrka (2010) emphasize that with a more trait-like measurement "people's environmental engagement can be predicted with up to 80–90%", in particular reflecting pro-social dispositions in relation to pro-environmental behavior (p. 72). In two different studies, greater environmental concern was related to greater openness and agreeableness (the tendency to be compassionate and cooperative rather than suspicious and antagonistic toward others) (Hirsh, 2010; Klein et al., 2019). In a wide-ranging set of studies, openness, agreeableness, and conscientiousness were strongly linked to environmental engagement across both individuals and nations (Milfont and Sibley, 2012). Conscientiousness is an important personality trait because a lack of it leads to impulsive behavior and a loss of self-control in the face of tempting unsustainable situations. This issue is also highly emphasized in the literature on "mindfulness" (see e.g., O'Brien, 2008; Amel et al., 2009; Ericson et al., 2014).

Related to consciousness is another important determinant of behavior, namely, *habits*. Habits are highly unconscious and embedded in routines and social practices (Heimlich and Ardoin, 2008; Southerton, 2013; Verplanken and Roy, 2016). They are difficult to change, as they are rewarding because they save time and energy (via the routines) and are a barrier to all kind of sustainable behaviors (Lewin, 1951; Stern, 2000; O'Riordan and Stoll-Kleemann, 2015). For example, many of our day-to-day food habits are routine, in that we eat often and without much deliberation, e.g., unsustainably caught fish. The trend toward "convenience" has been a major influence on food-purchasing habits, frequently accompanied by the excessive involvement of plastics, and encouraged by a lack of time, skills, or interest in cooking. This demonstrates how behaviors are facilitated by the structures of the production and supply systems. The so-called "Consumption-Happiness Myth," which is based on neuropsychological research, explains how we are locked in consumption patterns based on mechanisms like habit formation, which interact to influence "our sense of self at the very deepest levels of consciousness" (Brannigan, 2011, p. 85). Consumption is also viewed as a social marker to construct social identities and lifestyles. Overall, "habitual and routine forms of action are more than a matter of individual deficiencies" (Southerton, 2013, p. 16). They are also "socially conditioned and shaped by culturally derived dispositions" (ibid, p.17).

More "positive" factors toward effective ocean literacy are *self-efficacy* and *emotional involvement*. In the behavioral models reviewed, it emerged that self-efficacy is an important determinant for pro-environmental behavior (Gifford and Nilsson, 2014; summarized by Antonetti and Maklan, 2014). According to Ajzen (1991), self-efficacy is defined as the "perceived ease or difficulty of performing the behavior" (p. 188). People who feel they have the self-efficacy to carry out a certain behavior are more likely to do so than those who perceive themselves as lacking the ability to behave in the desired way. The notion of self-efficacy may also be a matter of consumer sovereignty and environmental responsibility (Peattie, 2010; Ericson et al., 2014; Fischer and Barth, 2014; Girod et al., 2014).

Emotional involvement, understood as the ability to experience an emotional reaction when experiencing the ocean positively (e.g., because of a person's connection with the sea) and negatively when confronted with the multi-facet impacts of human-made ocean degradation such as fear, empathy, or a bad conscience ("cognitive dissonance" see below), is of high importance for effective ocean literacy with the final aim of behavioral change (Jefferson et al., 2015). Kollmuss and Agyeman (2002) conclude, "the stronger a person's emotional reaction, the more likely that person will engage in a new behavior" (p. 254, see also e.g., Han et al., 2016 introducing the "value-belief-emotion-norm model"). Jefferson et al. (2015) add that "by understanding emotions, engagement can be more than a knowledge-transfer exercise and can inform approaches by talking to the heart, not to the mind"; (. . .) by taking "opportunities for connection and greater involvement through building on uniqueness of an area, feelings of pride and identity"; and by "reviving cultural and historical feelings toward the marine environment" (p. 64).

This establishes a link to what Fletcher and Potts (2007) have described as "deep learning" (see above), which can ultimately lead to positive feelings such as "enlightenment and renewal" on the basis of the understanding of how individual behavior affects the oceans, either positively or negatively. "Renewal suggests that changed behavior can renew the environment through exerting less pressure upon it. Potentially of equal importance is personal renewal through the enhanced sense of well-being the changed behavior can induce—through doing the right thing" (p. 515).

Unfortunately, the analysis of several studies on environmental and sustainable behavior shows that a mechanism called *cognitive dissonance* acts as a barrier to feeling emotionally involved or processing new information adequately—and thus to behavioral change (Stoll-Kleemann et al., 2001; Stoll-Kleemann and Schmidt, 2017). Cognitive dissonance is a theory developed by Festinger (1957) in order to understand human behavior and, more specifically, human emotions. Following Kollmuss and Agyeman (2002), cognitive dissonance is also included in the conceptual model (see above) developed here. The literature reviewed confirms that people experience dissonance when they are reminded that their behavior may not match their values and attitudes, and the resolution of this tension by changing behavior (less fish/more sustainable fish/less or no plastic use/different consumption behavior, e.g., low-carbon oriented, etc.) is too painful or difficult (e.g., Stern, 2000; Thørgersen, 2004). However, people tend to avoid or resist information about the negative consequences of their unsustainable behavior because they contradict or threaten their basic perspectives on fairness and ethical behavior and can give rise to strong, emotionally distressing reactions (Stoll-Kleemann et al., 2001 and in detail, see below). Psychological responses aimed at relieving people of these negative feelings include denial and delegation as a means of removing feelings of guilt (e.g., Kollmuss and Agyeman, 2002; Bamberg and Möser, 2007; Antonetti and Maklan, 2014; Reese and Jacob, 2015; Han et al., 2016). Because people who delegate or deny are unlikely to change their behavior toward sustainability, it is important to look at these mechanisms to find solutions to overcoming them.

The concept of selective moral disengagement explains in greater detail how the process of cognitive re-construing or re-framing of "destructive" behavior as being morally acceptable without changing the behavior or the moral standards works (Bandura, 1999). At its core is the mechanism of convincing the self that ethical standards do not apply to oneself in a particular context by means of disabling the mechanism of self-condemnation (Bandura, 1999; Moore, 2015). Different psychosocial mechanisms support the undermining and neutralizing of moral control and operate at both, the individual and social-systems level: among them is diffusing of responsibility for detrimental behavior. Collective action, which makes one's contribution seem trivial, is a popular form of self-exoneration for aggregate harmful effects. People may see little harm in conducting ocean related but unsustainable behavior since the individual impact seems small since the resource is so huge in size. Now, however, the cumulative effects of these actions have resulted in harming the oceans (a classical "tragedy-of-the-commons situation" in which behavior "that makes sense from the individual point of view, when repeated by enough individuals, ultimately proves disastrous to society", Gardner and Stern, 1996, p. 23).

Displacement of responsibility is also problematic. Moral control operates most strongly when people acknowledge that they are contributors to harmful outcomes but this mechanism spares them self-disapproving reactions by shifting the responsibility to others or to situational circumstances. Social, economic and moral justifications sanctify harmful practices by investing them with worthy purposes. This enables people to preserve a sense of self-worth while causing harm by their activities, (Bandura, 2016). This practice is also omnipresent in political and everyday conversations encompassing beliefs such as the contention that significant consumption is necessary for maintaining jobs, or that eating (unsustainably caught) fish is necessary for a healthy diet.

Finally, it is important to mention the disregard, distortion or denial of harmful effects. Causality is difficult to gauge when the outcomes of behavioral practices are slowly cumulative and widely separated in time (Bandura, 2016). When people pursue activities that serve their interests but produce detrimental effects, they frequently attempt to avoid facing the harm they cause, or at least minimize it. If minimization does not work, the next strategy may be to discredit the scientific evidence of harm most prominently done for climate change (Bandura, 2007). Edvardsson Björnberg et al. (2017) point out that forms of organized denial can be easily detected: They encompass lobbying and propaganda performed by political, industrial and religious organizations and think-tanks. The "rationale for driving this grand denial project has been attributed to conservative ideology, vested interest in fossil fuels or a combination of these. Due to a misconceived application of the balancing principle in the media, denialist disinformation has been treated on par with scientific information" (p. 237).

External Factors

Socio-cultural factors

As pre-eminent socio-cultural factors, *culture, religion*, and the construction of *social identities* are influences that shape people's perceptions and behavior toward the ocean. According to Jefferson et al. (2015), it is essential to recognize the heterogeneity in society's connection with the sea—with influencing variables including age, gender, social values, or proximity to the coast (p. 62). By understanding public perceptions of the sea, particularly the ways in which people value and connect with the marine environment and the issues which affect it, it is, for example, easier to tailor marine-engagement campaigns. Santoro et al. (2017) add that ocean literacy has different meanings in different countries and culture and already in Europe with its many different basins and regional seas one has to consider different cultural contexts.

In the context of socio-cultural factors, it could happen that a group could have similar knowledge of a marine conservation issue but respond to different engagement approaches differently (Steel et al., 2005; Ostrom, 2009; Jefferson et al., 2015; Potts et al., 2016). Considering multiple variables of human behavior is inevitable, and in addition to the above-mentioned personal factors, this also applies to different cultural connections between society and the sea (for a list of factors see Ostrom, 2009). Jefferson et al. (2015) emphasize that the "cultural context is critical to understand how people engage with the sea. This was considered to enable a deeper appreciation of how the sea influences or is part of an audience's identity or sense of place" (p. 64). They illustrate the potential role of cultural/religious connections with an example from Bien Unido Reef Marine Park in the Philippines, which was threatened by blast- and cyanide-fishing. Placing religious statues underwater resulted in dramatic declines of illegal activities, thereby supporting the Park's marine-conservation objectives through the alignment of such priorities with cultural values (Jefferson et al., 2015).

Another interesting aspect related to culture—but also to the politico-economic sphere because power and agency play a role here—is the importance of gender. Gissi et al. (2018) suggest that "removing the cultural barriers of a male-dominated world for women to access governance of the oceans" will lead to achieving sustainability because "the marine environment and those dependent on it have much to gain from "blurring" lines or boundaries with regard to who has a mandate to govern ocean space and who has a say about the allocation of its resources" (p. 218). The authors built on an analysis of women's contributions in the maritime sectors, such as fisheries and marine conservation. It emerged that, e.g., "in conservation, women have frequently advocated for the common good, raising their voice for the common good. From studies on sustainability, it is clear that they are regarded as major actors of sustainable development due to their inclusiveness and collaborative roles" (p. 218).

Politico-Economic Factors

Sustainable ocean-related behavior would ideally require supportive government policies and practices, new and different business practices, and civil-society initiatives working in synergy. Many political agreements exist on various regional and sectoral levels to protect the environment, including the oceans and the climate, such as SDG 14, the UN Convention on the Law of the Seas (UNCLOS, 1982) on the international level, or the Water Framework Directive (European Commission, 2000) and the Directive for Maritime Spatial Planning and Integrated Coastal Management (European Commission., 2013), all on the European Union level, among others. In many cases, major implementation problems are based on a lack of political will such as observed by McCauley et al. (2019) for Ireland, where the government is slow to act on and implement marine-related issues and marine education.

Certainly the most depressing example when it comes to political failure concerning the implementation of important environmental and ocean-related agreements is the case of anthropogenic climate change (as one major threat to the oceans). For the Paris Agreement, which aims to limit global temperatures "well below" 2°C above pre-industrial levels, with the ultimate objective of reducing this to 1.5°C (UNFCCC, 2015), the probability of collective failure to achieve these goals is very high (Bandura, 2016; Bode, 2018). For example, to attain the 1.5°C pathway would involve immediate massive cuts in coal production and burning. Germany, the world's fourth-largest economy, is a concrete example of climate-policy failure: Its absolute coal use has increased in recent years by 11% (2009–2014), and it continues to provide significant subsidies to coal—and has even recently introduced new subsidies for coal-fired power (Climate Transparency, 2017; Whitley et al., 2017; Bode, 2018). The country will not stop burning coal until the year 2038. In addition, the GHG emissions of Germany's transport sector are also growing. This failure is caused by "lock-in" effects from existing and currently constructed energy and transport infrastructure (Klein, 2014; Bode, 2018).

In general, our current market-driven capitalistic system, with its fatal dependence on growth conceived to increase consumption in all areas of life, leading to wasteful consumerism, is a major cause of exceeding planetary boundaries, including ocean destruction. Overconsumption with its "overzealous acquisitive desire stems from a feeling of emptiness or meaninglessness in one's life and that material consumption is a form of self-medication to soothe these bad feelings" (Amel et al., 2009, p. 17). Related is the problem of aggressive advertisement that seeks to create new needs for "unnecessary" products; another is planned obsolescence (products with an artificially limited life span), which generates long-term sales by reducing the time between repeat purchases (O'Brien, 2008; Danciu, 2014; Ericson et al., 2014) and unsustainable options are still the default (Amel et al., 2009). Finally, widespread and, to a degree, very creatively masqueraded lobbying efforts based on strong interlacement with politics enjoy continuous significant success in shaping laws and weakening regulations in ways that work against any environmental-protection measures in a wider sense (Stern, 2000; Bandura, 2007; Billé et al., 2013; Danciu, 2014; Klein, 2014; O'Riordan and Stoll-Kleemann, 2015).

Some hope comes from Lubchenco et al. (2016), who report a few positive cases (generally being based on theoretical thoughts introduced by Eleanor Ostrom). On the local level, well-designed secure-access fisheries, also termed "rights-based fishery" (RBF), can convince individual fishers to undertake their work more sustainably. In 2016, there were already over 200 RBFs covering over 500 species in 40 countries (Lubchenco et al., 2016). The main mechanism consists of providing fishers with predictable access to a portion of the allocated harvest (either a share of the total allowable catch or an area in which to fish) with science-based catch limits, strong community engagement, and strong consideration of local conditions as essential success factors (ibid.). A completely different pathway—even on the national level—is to use debt-for-nature swaps as a way to reduce foreign debt in exchange for protection that includes oceans and their conservation (and not only for terrestrial systems as is generally common). "In 2015, the Republic of Seychelles exchanged US $27 million worth of debt, for example, for increasing marine protection of its exclusive economic zone (EEZ) from <1 to 30% (400,000 km^2) through the creation of the second-largest marine-protected area in the West Indian Ocean. (…) The debt-for-nature swap allows the Seychelles to invest in its own local coastal economy—fisheries and tourism—rather than sending the money to other countries to cover debt" (Lubchenco et al., 2016, p. 14510).

But in general, it is evident that global, regional, and national approaches to resolve the problems are limited, while individual behavior is proposed as a "key policy channel" because individuals can place pressure on politicians through recognized democratic channels to address environmental concerns. For this to happen, it would be necessary to increase the capacity, as well as to create a stronger public "desire" to be involved, e.g., in the management of the marine environment, in order to achieve a higher degree and more credible implementation of environmental policies and international agreements. Of course, it must be admitted that this can be challenging because, particularly in the case of oceans, there are multiple nations bordering them, each with its own approach to ocean protection and cultural attitude toward individual responsibility, pro-environmental behavior, and lifestyle (Fletcher and Potts, 2007; McKinley and Fletcher, 2010, 2012).

DISCUSSION

Feasible Options and Incentives Toward Ocean-Friendly Behavior

Although it seems nearly impossible to change the overall current economic system, Lubchenco et al. (2016) show that an approach based on increasing reputation and toward a positive self-image can create conditions that also incentivize companies and countries, and not only individuals, to engage in activities that support sustainability. For example, marine reserves, which are "generally lobbied strongly against by powerful extractive industries (fishing, oil, gas, and mining)" and whose designation has been very difficult in the past, are now getting more support because of the announcement of a competition among global leaders to create the world's largest marine reserve. A second example—with the aim of improving fishery sustainability in the business sector—has been the pledge by large retailers to only source seafood products certified as sustainable. The result is that "more than 80% of North American retail and institutional food-service enterprises have seafood- sustainability policies, in partnership with environmental non-government organizations" (Lubchenco et al., 2016, p. 14512).

Although, ways to promote ocean-friendly behavior might include the provision of information about the consequences of unhealthy oceans and concrete ways of achieving a more intact marine environment, it makes no sense to simply address rational cognitive issues (Markowitz and Shariff, 2012; Bolderdijk et al., 2013; Darnton and Evans, 2013, p. 13; O'Riordan and Stoll-Kleemann, 2015; Han et al., 2016). It is better to include more emotional and "feeling" elements in choices regarding ocean-relevant behavior. Feelings regarding responsibility and guilt are particularly important because they are strongly connected to the willingness to make sacrifices for the environment (Bamberg and Möser, 2007; Jefferson et al., 2015; Han et al., 2016). In addition, in particular pride, hope, and gratitude as positive (moral) emotions play a key role in driving support for action (Markowitz and Shariff, 2012; Antonetti and Maklan, 2014).

In this context, Lubchenco et al. (2016) point out that altruism, ethical values, and reciprocity are powerful drivers of change because the intrinsic desire of individuals for a positive self-image or to be seen by others in a certain positive way leads individual actors to do good to achieve personal satisfaction (see also Griskevicius et al., 2010). "This type of motivation can also apply when groups of actors work together to achieve a goal, creating a sense of camaraderie and shared investment that drives behavior. Even the perception of collective behavior can act as an incentive" (p. 14511; see also Barth et al., 2016).

In general, most people don't decide which behaviors to choose or which attitudes to hold based on a careful analysis (Cooney, 2011). Instead, people change their behavior through "the power of social modeling" and use the available information for their self-development (Bandura, 2016, p. 416). This is supported by Higgs (2015), who concludes that "humans have a highly developed capacity to learn from the behavior of others and to find the approval of others awarding and disapproval aversive." (p. 38). This is why approaches based on reputation and self-image of individual actors—reflecting larger social norms—work so well (Bamberg and Möser, 2007; Barth et al., 2016; Lubchenco et al., 2016).

In fact, a small number of people—innovators—are willing to try out new ideas and behaviors. Of course, new ideas and behaviors that are more "fit" than older ones can radiate, as a growing number of people gradually adopt them. If conditions are right, these "fitter" ideas gradually replace older beliefs for a substantial portion of society (Christakis and Fowler, 2009; Cooney, 2011). In the case of sustainable consumption behavior, such as eating less fish or meat and using fewer plastics, it is necessary that the perception of "losing" something (such as materialistic goods or comfort) needs to be reversed and transferred into a perception of gaining a "good life" relieved from unnecessary ubiquitous consumption and "fulfillment through non-consumer experiences" such as a re-connect to the pleasures of social life and feeling nature (Amel et al., 2009). Focusing on these innovators and on early adopters can help build up the number of supporters for sustainable ocean-related behavior until it reaches the critical growth stage. At this point, the power of social networks kicks in, and the majority of the public begins to accept these ideas and behaviors due to having heard about them from friends and neighbors and having observed them in these people's own behavior (Christakis and Fowler, 2009; Barth et al., 2016).

One additional approach in support of this process can be facilitated by techniques used in community-based social marketing (Barr et al., 2011; Stoll-Kleemann and Schmidt, 2017). Findings from neuroscience also support the usefulness of social-marketing strategies to influence our ocean-related behaviors, e.g., because they are able to limit the Consumption-Happiness Myth (Brannigan, 2011). Although social marketing "takes a page from the playbook of traditional advertising" to create behavior change (Cooney, 2011, p. 171), it is rather based on the idea that norms, commitment, and social diffusion have at their core the interactions of individuals in a community and aim at developing supportive social interaction (McKenzie-Mohr, 2000).

Similarly, Noppers et al. (2014) found that "the more people think that adopting a sustainable innovation has positive outcomes for their self-identity and social status, the more likely they are to adopt sustainable innovations" (p. 60). Because some people see ocean-friendly behaviors as this type of sustainable innovations, this seems to be a very promising approach. The authors recommend that "targeting symbolic attributes might need subtle and indirect methods as well" and employing lessons that "can possibly be drawn from promotion strategies of high-status and innovative brands" (ibid., p. 61). One remarkable example is the conservation-marketing effort described below, which is successful in its specific pursuit of this line in promoting sustainable fish and cosmetics and influencing others to follow.

Although research on social networks demonstrates that whenever we get one person to make a change, it "will likely lead others to make a change, and we are more successful than we think," some people—namely, opinion leaders and "connectors"—are linked to and can reach out to many more people than others; they are therefore much more influential than the average person (Cooney, 2011, p. 152f;Christakis and Fowler, 2009). Connectors are people who have a large number of contacts across an array of social, cultural, professional, and economic circles and make a habit of introducing people who work or live in different circles to each other (Gladwell, 2000; Christakis and Fowler, 2009). Opinion leaders such as politicians, prominent business people or entertainers, and religious and civic leaders are also directly linked to a large number of people, but their biggest impact is in transmitting social norms through the culture, public-policy decisions and the social media (such as Twitter), with the latter ones getting more and more importance, also in the area of ocean literacy (see e.g., Wright et al., 2015; Kopke et al., 2019). Getting opinion leaders to support the idea of ocean-friendly behavior is a critical step in the diffusion process. The success story below shows how this can work in practice. In this case, role models' actions helped reduce an unsustainable behavior (flying) and launched a whole new movement on not flying in Sweden.

The "conventional" media (such as the TV) still play an important role because they "take in stories and attitudes from other people and transmit them as social norms to a huge audience" (Cooney, 2011, p. 166). For example, long-running serial dramas can serve as principal vehicles for promoting personal and social changes because "by dramatizing alternative behaviors and their effects on the characters' lives, the dramas help people make informed choices in their own lives. (...) Story lines that dramatize viewers' everyday lives and functional solutions get them deeply involved. Unlike brief exposures to media presentations that typically leave most viewers untouched, ongoing engagement in the evolving lives of models provides numerous opportunities to learn from them" (Bandura, 2016, p. 419f).

Two Success Stories

"Air-Travel Shaming"

The first example, not directly related to the oceans but to climate change, which—as mentioned—is highly influential in causing all kinds of ocean-related harms. In Sweden, a phenomenon called "air-travel shaming" has appeared in relation to flying, an individual behavior whose sum total causes a very high CO_2 footprint and therefore harms other people, who are affected by the negative consequences of climate change. The process probably started with the successful biathlete Björn Ferry, a national celebrity who stopped flying some years ago. He now travels at least 13,000 km annually by train to competitions and his TV job as a commentator. No one in his family has flown for 2 years, and his wife and he are determined to live a completely fossil-free lifestyle by 2025. Another well-known Swedish opinion leader who understands the gravity of the issue is the country's Minister of Education and Cultural affairs, Alice Bah Kuhnke. In May 2018, she undertook official visits to Paris, Cannes, and Berlin by train. In fact, politicians across Sweden's entire political spectrum have committed themselves to giving up flying whenever possible.

The media have supported this trend, and the cultural editor of the nationwide newspaper Expressen recently decried the "idiotic lifestyle" of frequent flyers as the "most expensive suicide in world history." Researchers and artists have also registered their opinions, and a German newspaper commenting on the issue (Wolff, 2018) reports that for some, flying is no longer an alternative: jobs for which flying is obligatory are simply turned down.

Indeed, the Swedish railway system has witnessed a sharp increase in passenger numbers, whereas domestic and charter-flight passenger figures are dropping. Other indicators of the movement's growing acceptance include a Facebook group dedicated to providing tips on long-distance train travel, whose membership has grown quickly to 30,000. And the Swedish expression "air-travel shaming" (flygskam) is quite likely to become the country's Word of the Year (Deutsche Welle, 2018). With this, Sweden truly serves as an example of the establishment of new social norms toward low-carbon behavior that can certainly apply to more ocean-related behaviors as well.

"Project Ocean" (Summarized From Wright et al., 2015)

The second example is a conservation-marketing experiment called "Project Ocean," which has been running since May 2011, consisting of a partnership between the luxury London department store Selfridges and the Zoological Society of London (ZSL). It is based on the concept of "retail activism" in which 22 non-profit organizations, in which celebrities, scientists, royalty, fishing industry representatives, youth group leaders, parliamentarians, heads of state, artists, fashion designers, and musicians have been brought together. Key messages of the campaign were aimed at "catching people's attention, such as giant panda "swimming" next to a southern bluefin tuna with the message "You wouldn't eat a panda" (Selfridges, 2019). This illustrated that this tuna species is more threatened than the giant panda. Activities to raise awareness extended throughout the store with consistent messages presented in a variety of ways, including art installations, interactive displays and a live exhibit, again guided by ZSL for technical content. These highlighted threats to marine ecosystems and conservation solutions the customer could engage with through informed purchasing choices and donating funds" (Wright et al., 2015, p. 45).

Selfridges changed their purchasing practices to select only sustainable seafood and provided tools to inform their customers how to do the same. The effort resulted in increased awareness among buyers as to the fish species they should eat. It also encompassed the recommendation that products containing shark oil should be eliminated from beauty products they purchased. Selfridges led by example and thus influenced the behavior of many of its suppliers, including their in-store franchises, as well as a sushi restaurant chain that switched to sustainable seafood both in its Selfridges branch and across their 80 UK restaurants as a result of Project Ocean. Selfridges has also addressed the issue of marine plastics through better retail "plastic practice" in a further campaign from 2015 on (Wright et al., 2015, p. 45).

CONCLUSIONS

In order to achieve effective ocean literacy, it is necessary to successfully activate sustainable ocean-friendly behavior. Providing knowledge on human-ocean interactions is only one piece in the jigsaw puzzle (Gifford, 2011; Bolderdijk et al., 2013) and some researchers even point out that "moral and educational approaches have generally disappointing track records, and even incentive- and community-based approaches rarely produce much change on their own" (Stern, 2000, p. 419). Instead, Stern (2000) continues "the most effective behavior change programs involve combinations of intervention types. These findings underline the limits of single-variable explanations for informing efforts at behavior change. The behavior is determined by multiple variables, sometimes in interaction" (p. 419).

Having this in mind, e.g., acknowledging women's roles in ocean issues for its effectiveness is an important contribution. Furthermore, moral disengagement needs to be overcome, since it is a key determinant of behavior harming the oceans, with its associated mechanisms such as diffusion and displacement of responsibility, moral economic and social justification, and disregard of harmful consequences. Moral disengagement may be lessened by the promotion of new social norms related to ocean-friendly behavior and their dissemination via social networks and other channels—as shown in the two success stories. If it were the "norm" to consume sustainable fish only, and not to fly or use plastics, or even to consume less and more sustainably in general, habits could be readjusted and become embedded in social practices and form a "new conformity." Realizing that small reductions are still very important in a collective behavior sphere, coupled with a strong sense of "starting together" and establishing a collective efficacy instead of waiting for others to act first, will remove the fear of individual sacrifices. In this way, feelings of a new social identity and more accommodative lifestyles may begin to appear.

To sum up, individuals can avoid damage to the oceans through modified lifestyle choice and behavioral change, leading to collectively improved ocean health. In return "for modified personal behavior, citizens will receive the benefits of healthy oceans, which may include enhanced resource options, aesthetic improvements to coastal areas, improved water quality, and ethical and moral benefits" (Fletcher and Potts, 2007, p. 513).

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The author confirms being the sole contributor of this work and has approved it for publication.

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A Change of Mind: Applying Social and Behavioral Research Methods to the Assessment of the Effectiveness of Ocean Literacy Initiatives

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Assessment of environmental literacy and ocean literacy focus on increasing knowledge and awareness. The goal of ocean literacy initiatives is ultimately to enable behavior change (whereby citizens take direct and sustainable action) to achieve sustainable solutions to marine environment issues. The application of social and behavioral research methods provides powerful tools for assessing if ocean literacy initiatives are effective at increasing participant's knowledge and awareness of an issue, its causes and consequences and behaviors or actions required to enable sustainable solutions. Social and behavioral research methods also provide a means of assessing changes in attitude, a key predictor of behavior change, and ultimately a means of assessing changes in a participants intended and reported behaviors. We present a framework to integrate social and behavioral research methods within assessment of the effectiveness of ocean literacy initiatives. The before and after assessment we undertake develops existing environmental literacy and ocean literacy assessment approaches by integrating social and behavioral research methods to assess key predictors of behavior change. We structured the assessment methodology within a Theory of Change logic model, to provide a protocol for systematic evaluation of ocean literacy initiatives and tools. Specifically those aimed at promoting specific behavior change objectives for pre-identified actors. Assessment of educational training courses for professionals entering the shipping industry (targeting behaviors to reduce the spread of invasive species), and educational workshops for school students (aged 11–15 and 16–18), on problems related to marine litter and microplastics and potential solutions were assessed using the framework. Through before and after surveys, an increase in awareness, knowledge and an increase in attitudes supporting action to reduce impacts on the marine environment were reported by participants, after interaction with sets of tools developed by the Horizon 2020 Ocean Literacy project *ResponSEAble*. Results supported the importance of targeting specific audiences with tailored ocean literacy tools and the importance of informing actors of issues and solutions within the context of wider ocean literacy principles.

Keywords: ocean literacy, behavioral science, effectiveness, education, attitude, sustainable development, intended behavior

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INTRODUCTION

The concept of Ocean Literacy, defined as, "understanding the oceans influence on you and your influence on the ocean." Schoedinger et al. (2005) underpins the concept of environmental or ocean or marine citizenship. "Ocean citizens" make informed lifestyle choices to minimize impacts on ocean health, and in so doing, contribute to solutions for large scale and seemingly insurmountable global problems (Hawthorne and Alabaster, 1999; Fletcher and Potts, 2007). Thereby, increasing ocean literacy across public, industry and governance actors provides a society-wide approach, to reduce environmental impacts and pro-actively generate positive change. As a result, negative implications for human societies, such as impacts on economic resources and human health are reduced. Within the United Nations revised roadmap for the "decade of ocean science for sustainable development," ocean literacy underpins targets for citizens and stakeholders to have a more responsible and informed behavior toward the ocean and its resources (United Nations, 2018).

Enhancing ocean awareness and knowledge is considered essential to increase support for solutions to reduce or cope with human impacts on the marine environment (Schoedinger et al., 2005). However, to reduce human impacts requires larger scale behavior change. As such, assessment of environmental or ocean literacy education and awareness raising interventions has begun to focus on changes in participant's attitude and behavior (Hartley et al., 2015, 2018a). Attitude and behavior changes, whereby, public and industry actions provide support for solutions to environmental problems, and take action, are, central to the goal of forming an ocean literate society. Collective action, stimulated by awareness, but fuelled by knowledge of behavior options to reduce impact and the attitude to take them, provides an opportunity to allow human impacts on the marine environment to be tackled over large scales, and enable sustainable development goals to be met (Hawthorne and Alabaster, 1999; Fletcher and Potts, 2007; United Nations, 2018).

The United Nations revised roadmap for the "decade of ocean science for sustainable development" identifies, under Research and Design Priority Area 7, that; "*a rigorous ocean literacy programme of activities has to be designed. The major target audiences have to be school students, which requires including ocean literacy in the school curriculum, reaching out to decision-makers, governmental authorities, and the public at large*" (United Nations, 2018). At a global scale the roadmap identifies the need to build capacities worldwide, including that; "*all nations, stakeholders and citizens have access to ocean data and information, technologies and have the capacities to inform their decisions*" (United Nations, 2018). To enable governments, stakeholders and citizens to undertake informed decisions the road map identified the importance of ocean literacy in Objective 1 of the strategic objectives; "*To generate knowledge of the ocean system, its role in the earth and climate system, including the human component, its biodiversity and the seabed, to support sustainable management*" (United Nations, 2018). The roadmap identifies that, for the public in particular; "*increased awareness and ocean literacy will be instrumental in triggering behavioural changes, such as adaptation of lifestyles, joining non-government organisations (NGOs), choosing ocean-affiliated professions*" (United Nations, 2018). Although an ocean literacy programme has already been identified as essential to increase in awareness and knowledge, and lead to informed decision making and to trigger behavior changes, assessment of effectiveness will be essential to ensure objectives are met. Assessment will be required to monitor if the initiatives within an ocean literacy programme achieve intended increases in awareness, knowledge and inform decisions and trigger behavior change.

Over the last decade, ocean literacy has largely focused on the development of education and engagement materials, for classrooms use and for the general public, including campaigns and messages communicated thorough media, exhibitions, film-making and story-telling (Schubel and Schubel, 2008; Bishop et al., 2015; Donert et al., 2015). Assessment of effectiveness of these activities has focused on assessing awareness and knowledge in relation to defined levels of ocean literacy (Schoedinger et al., 2005; Fauville et al., 2018). Existing perceptions of the public and other actors on relative importance of pressures on the marine environment, and concern regarding impacts have received attention (Gelcich et al., 2014; Potts et al., 2016; Buckley et al., 2017). Pre-existing pro-environmental behaviors undertaken by people have also been studied, as well as the relationship between level of knowledge, concern and the existing behaviors or actions undertaken (Muderrisoglu and Altanlar, 2011; Chen and Tsai, 2016). However, the effect of an ocean literacy initiative on behavior change objectives, for a given audience or actor are rarely assessed, despite the availability of behavioral and social science methods to achieve this (Hartley et al., 2015, 2018a; Pahl and Wyles, 2017).

Examples of cross-disciplinary research methods, to assess behavior change, already exist and have been applied in recent years for conservation projects (Andriamalala et al., 2013; Saypanya et al., 2013; Chaigneau and Daw, 2015), environmental literacy assessment (Muderrisoglu and Altanlar, 2011; Chen and Tsai, 2016) and ocean literacy interventions (Hartley et al., 2015, 2018a,b). Behavioral models used in these studies have been adapted from well-established approaches developed in behavioral sciences for effectiveness of health interventions and environmental education (Prochaska et al., 1992; Vaughan and Rogers, 2000; Jenks et al., 2010).

Systematic approaches to assessing change in attitude and behavior are valuable both in assessing the effectiveness of ocean literacy tools and for informing practitioners on the benefit of applying tools with specific audiences. Pahl and Wyles (2017) highlight that information (informing people) is sometimes considered as the key factor for changing perceptions and behavior by scientists outside of the behavioral sciences. Informing people (raising awareness) is a necessary step, but studies have revealed assessing awareness alone does not necessarily assess if a change in attitude and behavior has been adopted (Schultz, 1999; Steg et al., 2013). Pahl and Wyles (2017) conclude that understanding the influences of human thought and behavior is just as important. Incorporating existing systematic understanding of human behaviors and their underlying mechanisms, with empirical methods to collect data that explain perceptions and behavior, thereby, enables a greater level of assessment of interventions aimed at behavior change (Reddy et al., 2016; Pahl and Wyles, 2017).

The application of behavioral models and research techniques from psychology and behavioral sciences provides the opportunity for a greater level of understanding of uptake of messages from ocean literacy education tools. Most importantly, the research techniques allow for assessment of predictors of behavior change, including change in intended behavior. Perceived behavior control ("it is up to me whether I do this rather than other people or contextual factors") and intended behavior ("I will do this") were identified through review of environmental behavioral studies as the best direct predictors of behavior (Klöckner, 2013), and can be monitored through behavioral research techniques (Pahl and Wyles, 2017).

Both psychological research techniques and environmental literacy approaches such as the Environmental Literacy Ladder (ELL, 2007), identify the process or stages that are needed to be reached to achieve the end objective. This approach, starting with the end objective and working back through the stages that lead to it, can be effectively summarized in the Theory of Change approach (Connell and Kubisch, 1998). The Theory of Change logic model, maps out a path of how the desired behavior change, promoted by the ocean literacy initiatives, would be achieved (Connell and Kubisch, 1998). Saypanya et al. (2013) and Andriamalala et al. (2013) successfully applied a Theory of Change adapted from health research (Prochaska et al., 1992; Vaughan and Rogers, 2000; Jenks et al., 2010), to take a structured, systematic approach to achieving behavior change (support for conservation initiatives) in fishing communities and rural hunting communities in Madagascar and south-east Asia. The approach has resulted in reduction of hunting pressure on rare and endangered species and fishing pressures and fish stocks as a part of conservation programmes.

Each stage in a Theory of Change provides a step toward the ultimate objective (e.g., large-scale behavior change) (Connell and Kubisch, 1998; Jenks et al., 2010). Each step can be assessed by an indicator metric, in relation to the stated objective. Indicators and objectives can include responses to surveys, or quantitative evidence, such as an increased proportion of participants recycling or reducing purchase of single use plastic.

We applied a Theory of Change logic model to enable a systematic assessment of ocean literacy initiatives. Each stage in the Theory of Change moved toward the behavior change objective identified for the ocean literacy initiative. The stages moved from development of participant's knowledge of causes of the issues and the resulting consequences for marine life and human society, changes in their attitude to changes to their intention to take actions to address the issue. Each of these stages relate to predictors of behavior change, identified in behavioral science literature (Klöckner, 2013; Pahl and Wyles, 2017), and stages within the environmental literacy ladder (ELL, 2007). The aim of the work carried out, was to apply social and behavioral research methods, to assess the effectiveness of ocean literacy initiatives on influencing predictors of behavior change (Klöckner, 2013; Pahl and Wyles, 2017), and ultimately behavior post interaction with the intervention. The approach aims to build on existing studies of links between awareness, knowledge and concern for ocean environment issues (Gelcich et al., 2014; Buckley et al., 2017), studies of people's attitudes and pro-environmental behavior (Muderrisoglu and Altanlar, 2011) and changes in behavior post interaction with education tools (Hartley et al., 2015, 2018a).

To demonstrate the framework's application to assessment of ocean literacy education and awareness raising tools, the use of the Theory of Change logic model was demonstrated in two pilot studies. We assessed the effectiveness of "sustainable seafaring" educational courses undertaken by students training to become engineering and deck officers in the shipping industry, at a technical college in Basque Autonomous Community (aged 16–25) (Study 1). We also assessed the effectiveness of ocean literacy films shown during educational workshops, at an aquarium in the UK, undertaken by school pupils (aged 11–15) and workshops undertaken by school aged students (11–15) and older teenagers (16–18) in Tulcea, Romania (Study 2). In the pilot studies we used a survey instrument, provided to participants pre and post interaction with the ocean literacy initiative, adapting the methods of Hartley et al. (2018a) to answer the following questions:

1. Do the ocean literacy tools influence predictors of behavior change?
2. Which predictor of behavior change shows the strongest relationship to participants support for behaviors promoted by the ocean literacy tool?
   i) Does level of awareness and knowledge influence intended behavior?
   ii) Does level of concern (attitude) influence intended behavior?
   iii) Does perceived self-efficacy (confidence in ability to undertake the action or behavior) influence intended behavior?

METHODS

Relating Predictors of Behavior Change to Ocean Literacy Tool Objectives

We aligned the stages within the ELL (ELL, 2007), and the results of an integrative model, tested by Klöckner (2013), which identified the best predictors of environmentally conscious behavior, based on data from 56 data sets targeting different environmental behaviors (**Table 1**). The ten social and psychological concepts identified by Klöckner (2013) can be measured and distinguished empirically and provide a rich toolbox for changing behavior beyond information and knowledge provision (Pahl and Wyles, 2017). These provided the basis for "ocean literacy dimensions" that were applied as stages within the Theory of Change model adapted from health and conservation projects (Jenks et al., 2010; Saypanya et al., 2013) (**Table 1**).

Defining Ocean Literacy Initiative (Tool) Objectives

The ocean literacy educational and awareness raising initiatives (tools) we assessed were developed to address specific behavior

TABLE 1 | Relationship between predictors of behavior change identified by Klöckner (2013), the ELL, TofC categories, and OL dimensions applied in this study.

Predictors of behavior (Klöckner, 2013)		Environmental Literacy Ladder (ELL). (Text in brackets indicates an in-direct connection)	Theory of change stages 1–5 applied in conservation campaigns	Ocean literacy dimensions applied in assessment of effectiveness of ocean literacy tools
Best direct predictors of behavior	**Intentions** ("I will do this")	**Collective action:** capacity for personal and collection action and civic participation	Behavior	**Behavior decisions, choices, actions, and habits**, with respect to ocean related issues (either intended behavior "I will do," self-reported behavior "I do" and level of repetition of behavior). **Attitude (self-efficacy)**: A belief in own ability to address the issue and that personal actions will be effective. **Activism**, the degree to which a person engages in protesting and campaigning to bring about political and social change
	Perceived behavior control ("It is up to me whether I do this rather than other people or contextual factors")	**Skills:** problem solving and critical thinking skills		
	Habits (behaviors that have become automatized through repetition)	(Collective action)		
Factors having an indirect effect on behavior	**Norms** (what is seen as commonly done by others)	(Collective action)	Communication/ social norm	**Communication:** extent to which a person engages with ocean related information and how much they communicate about the ocean with family and friends (influence of the social norm)
	Attitudes (favorable or unfavorable evaluations)	**Attitudes**: of appreciation and concern for the environment	**Attitude**	**Attitude:** level of agreement with (favorable or unfavorable evaluations) or concern for a particular position, related to impacts and welfare in the DAPSIWR framework i.e., they exist, they are important, and a response is needed
	Responsibility (ascriptions of who should deal with the problem)	(Attitude)	Attitude	**Attitude (self-efficacy)**: A belief in own ability to address the issue and that personal actions will be effective
	Negative and positive emotions (such as worry or hope)	(Attitude)	Attitude	**Attitude:** Concern or worry about the issue
	Values (general trans-situational goals such as equality or individualism)	(Attitude)	Attitude	**Attitude:** Belief that it is important that society and individuals take actions to reduce or cope with the issue
	Whether people see themselves as environmentalists	(Attitude)	Attitude	**Environmental connectedness:** Emotional response to marine issues. **Activism:** the degree to which a person engages in protesting and campaigning to bring about political and social change
	Awareness of consequences (knowledge about impacts)	**Knowledge,** and understanding of human and natural systems and processes	Knowledge	**Knowledge**: What a person knows about an ocean related topic and the links between topics (such as knowledge about impacts of human actions on the ocean environment)
		Awareness: general awareness of the relationship between the environment and human life	Awareness	**Awareness:** Basic knowledge that a situation, problem or concept exists

change objectives, for specific actors in relation to key ocean literacy topics. The first tool, a 2 day course to educate young career professionals working as engineers or deck officers on board large ships focused on addressing the transport of introduction of invasive non-native species (as larvae) in ballast water. The second focused on addressing the issue of microplastics entering the sea through consumer's use of cosmetic products containing microplastics (**Table 2**).

The information within the tools and the actors to be targeted were selected through identifying actors and behavior change responses that could potentially have a large impact on reducing the negative impacts. These were identified through analysis of the interactions between the human and ocean systems, adapting the Driver–Activity–Pressure–State–Impact–Welfare (impact)–Response (DAPSI(W)R) causal models (ResponSEAble, 2015; Elliott et al., 2017). In essence, the DAPSIWR approach provided the pre-intervention design and assessment process to identify the audience, and the behavior change message to reach objectives within behavior science planning and evaluation frameworks, such as the PRECEDE- PROCEED model (Green and Kreuter, 1999) and guiding questions identified by Reddy et al. (2016).

Education Materials

Study 1. Two Day "Sustainable Seafaring" Course

The "sustainable seafaring" course was developed within the ResponSEAble project by environmental education professionals, the "ProSea Foundation." The course was designed for students training as engineering and deck officers and early career professionals in the shipping industry. The course contained lecture material, short films, and group workshops and quizzes to provide background knowledge on marine ecology, including food webs and productivity in coastal and deep pelagic seas. Background knowledge was provided on ballast water treatment and International policy (compliance with the Ballast Water Management Convention standards). Case studies of impacts of invasive non-native species on the marine environment and human livelihoods were also provided. The economic benefits to the industry of ensuring ships and shipping businesses minimize environmental impacts were then discussed, in relation to people, planet and profit models. Participants were asked to discuss sustainability issues in workshops and groups. In particular, participants were asked to discuss actions they can take when working in roles as engineering or deck officers to aid sustainable seafaring. The courses aimed to highlight the profitability of companies that act sustainably and the advantages not only to the marine environment and human livelihoods, but to the competitiveness of shipping companies that operate sustainably in the eyes of clients.

Study 2. Short Film (5 min) Produced by Professional Environment and Sustainability Filmmakers on the Topic of Microplastics

The short film "*Rethinking Plastic*" was produced by the charity "TVE, Television for the Environment" within the ResponSEAble project. The film used interviews with leading academic experts, businesses and environmental charities and campaign groups that represent actors identified in the DAPSIWR causal model developed for the key story "microplastics" (specifically microplastics in cosmetics) (ResponSEAble, 2015). The film provided clear messages on the drivers of microplastic production, the activities supporting their use and the pressures on the state of the marine environment that leads to negative impacts on marine organisms, the environment and potentially human health and welfare. Responses were presented that can be undertaken by consumers, businesses, product manufacturers and local and national governments. It was designed to be appropriate for school students over 11 and general public of different ages, backgrounds, levels of knowledge and from different cultures. The film promoted specific actions viewers could take to reduce use and negative impact of microplastics in the marine environment. The film was shown as part of marine plastic and microplastic educational activities within the National Marine Aquarium, to school students aged 11–15.

Construction of a Theory of Change Logic Model

A Theory of Change logic model was constructed for assessment of ocean literacy initiatives within this study through collaboration with social and behavioral science researchers, tool developers and practitioners. The Theory of Change logic model identified the process by which the behavior change objective of the ocean literacy tool could be reached for the given audience. The Theory of Change steps related to predictors of behavior change identified in **Table 1**. Each stage in the Theory of Change models for both ocean literacy tools were discussed and objectives and indicators were set prior to the participants' interaction with the ocean literacy tool. The Theory of Change model for the "sustainable seafaring" education course for young professionals (conducted in Pasaia, Basque Autonomous Community, Spain) is displayed in **Table 3**. The Theory of Change model for the educational videos presented within workshops for school pupils (aged 11–15) (conducted at the National Marine Aquarium, Plymouth, UK) is displayed in **Table 4**.

Participants and Recruitment

In Study 1, a total of 17 students aged 18–44, participated from a technical college in Pasiaia, Basque Autonomous Community. The participants were recruited by course leaders and head teachers at the technical college, and were all in their final months of study before entering the shipping industry.

In Study 2, a total of 20 school students aged 12–15 years, participated in a viewing of the film "*Rethinking Plastic*" at an aquarium in Plymouth, UK. School students were recruited for the film viewing, from attendees of events run for UK teenagers as part of the aquariums "teen club" Ocean Squad events. The week long events are advertised nationally and participants can book on the aquarium website. Two workshop events, where the film was shown to participating students, were also run at two separate high schools (11–18 year old students), in Tulcea, Romania, organized in collaboration with teachers at the two schools.

Although sample sizes were small, all attendees at the events were provided opportunity to complete surveys. As this study intended to demonstrate the applicability of the assessment approach to assess effectiveness of an ocean literacy tool on a target audience, the results are relevant for the participant's, but the small sample size limits interpretation of the results in relation to a wider population. As only one set of participants interacting with the ocean literacy initiative completed surveys, we recognize the risk of not detecting influence of outside events or being able to increase confidence in results of effectiveness across different samples. Results were interpreted with caution and Bonferroni corrections were applied to ensure interpretations of significance of changes between pre and post results were conservative.

TABLE 2 | Actors and behavior change objective identified in the DAPSIWR process to have influence on addressing negative human-ocean impacts in relation to the key story topic (ResponSEAble, 2015).

Key story	Influential actor identified in DAPSIWR	Behavior change objective identified in DAPSIWR	Tool designed for education and awareness raising (ocean literacy) for relevant actor
Microplastics in cosmetics	General public and school pupils (aged 11–15)	Reduce or eliminate use of cosmetics containing microplastics	Educational films (based on DAPSIWR) incorporated in aquarium workshops
Invasive non-native species in ballast water	Young professionals (seafarers) training to enter shipping industry	Support introduction of ballast water cleaning systems and engage in best practice in their operation	Two day educational courses on workshops on sustainable seafaring: including sections on ballast water management and implications of spreading invasive non-native species

Survey Instrument to Assess Effectiveness of Ocean Literacy Tools

Questions were informed by environmental psychology and education literature, to address the ocean literacy dimensions identified in **Table 2**. The survey instrument formed a quantitative evaluation that participants completed before they began the training course or film viewing (pre) and again after (post). It took approximately 10 min to answer these questions. The study was introduced, including an explanation of the informed consent process, by course leaders, prior to the survey being completed. Consent was sought from participants to participate in the studies prior to completing the questionnaire. Participant's were reminded that the survey was not a test and that their answers were anonymous and only their honest opinion was being asked for.

Survey Question Development

Questions were based on Hartley et al. (2015) with additional questions based on predictors of behavior change identified by Klöckner (2013). Question wording was adjusted to the topics approached by the ocean literacy education tools. Questions were developed with pre-test groups at University of Plymouth and Oceanopolis Aquarium, Brest. Language of questions was adjusted following feedback from the pre-test groups, to make understanding clearer. For instance, each questions language was adjusted to be jargon-free, unambiguous, and focused on a single issue per statement, if confusion was reported or observed in the pre-test groups. Language of end points of the 0–10 scale were also adjusted in this process to make extremes of viewpoints as clear as possible.

Questions were developed from existing proven measures and their face validity as a measure of knowledge, attitude, and intended behavior specifically, was reviewed in respect to original source questions. Content validity was maintained through application of the Theory of Change, relating to the predictors of behavior change identified in behavioral science literature, with each question measure relating to an indicator of an objective within the Theory of Change. Results of the pre-test and the pilot studies were compared to results for similar knowledge, attitude and intended behavior measures, undertaken with study participants of comparable age and social background to assess convergent validity.

Internal reliability was assessed across the set of 5 intended behavior options provided by respondents to surveys before and after viewing the "Rethinking Plastic" film. Cronbach's coefficient alpha was calculated with a reliability coefficient of >0.70 considered as an indicator that the intended behavior measures were acceptable (Cronbach, 1990; Beanland et al., 1999; Pilot and Hungler, 1999). Cronbach's alpha identifies how closely related a set of items are as a group, and provides a measure of scale reliability. As all behavior actions relate to reducing or coping with a specific marine environmental issue, participant's responses to each individual behavior, would be expected, when combined, to be closely related to addressing the issue as a whole (a result between 0 and 1 of >0.70).

Study 1 Questionnaire

The pre-course questionnaire included eighteen questions. The questions were designed to assess participants' awareness of the issue, concern, knowledge, perceived understanding, belief and values, confidence and self-efficacy, communication about the issue, responsibility, and self-reported behaviors in relation to reducing or coping with the impacts of invasive non-native species within ballast water. Further questions were designed to assess factors relating to participants' age, location, occupation, pre-existing concern for marine environmental issues and feedback on sources of information on environmental issues. (e.g., "*I feel capable that when I start to work as a seafarer, I can reduce the spread of invasive species through my everyday actions*").

Participants were asked to indicate their (dis)agreement with statements, or level of concern, or frequency of stated actions with response options from 0 to 10, with end anchor points labeled "*completely disagree,*" "*not at all concerned,*" "*not at all,*" and "*completely agree,*" "*very concerned,*" "*all the time*." Mid anchor points were included to guide participants following feedback from pilot studies ("*neither agree/disagree,*" "*moderately concerned,*" "*some of the time*"). The post-course questionnaire included the same questions as the pre-course questionnaire. Present tense was changed to future tense in relation to behavior questions to assess participants' intended behavior once they work as a seafarer.

Study 2 Questionnaire

A shorter survey tool, based on the same question design as Study 1 was used, but with a smaller range of questions and simplified

TABLE 3 | Theory of Change model for the "sustainable seafaring" education course for young professionals.

Sustainable shipping course theory of change	Problem awareness	Knowledge	Attitude	Attitude—self efficacy	Interpersonal communication/social norm	Behavior change
Theory of Change: AIM	Following the intervention participants will be aware (informed) of the issue or problem in the key story	Following the intervention knowledge about the issue (key story) will have increased	Following the intervention attitude toward the issue would have changed, and change in behavior supported	Following the intervention participants feel the response action will be effective and they have the skills and knowledge required	Following the intervention participants will communicate about the issue or topic with friends, family and at work	Behavior adopted or intention expressed
Measurable objective	(i) After the course, mean response of shipping industry professionals (participants) to the question "*how informed about the effects of invasive species on the marine environment?"* (0–10 scale) will be ≥7. (ii) If pre course response is <7, effect size (Cohen's *d*) will show a medium or greater positive effect (≥0.8)	After the course, (i) mean agreement of participants to the statement "*I have good knowledge about how invasive species effect native marine life and how invasive species may affect human welfare.*" will be ≥7. (ii) If pre course response is <7, effect size (Cohen's *d*) will show a medium or greater positive effect (≥0.8). (iii) ≥75% of respondents will correctly answer the knowledge quiz question after the course	After the course, (i) mean response of participants to the question "*how concerned are you about the effects of invasive species on native marine life?"* (0–10 scale) will be ≥7. (ii) If pre course response is <7 effect size (Cohen's *d*) will show a medium or greater positive effect (≥0.8). (iii) mean agreement of participants to the statement "*I believe it will be better for the ocean environment and marine life, if ballast water is treated"* (0–10 scale) will be ≥7. (iv) If pre course response is <7, effect size (Cohen's *d*) will show a medium or greater positive effect (≥0.8)	After the course, (i) mean agreement of participants to the statement, "*I feel capable that when I start to work as a seafarer, I can reduce the spread of invasive species through my everyday actions,"* (0–10 scale) will be ≥7. (ii) If pre course response is <7, effect size (Cohen's *d*) will show a medium or greater positive effect (≥0.8)	After the course, (i) mean response of participants to the statement, "*How often do you talk about effective means of helping to reduce or cope with the effects of invasive species with family, friends, colleagues or teachers,"* (0–10 scale) will be ≥7. (ii) If pre course response is <7, effect size (Cohen's *d*) will show a medium or greater positive effect (≥0.8)	After the course, (i) mean response of participants reporting that they *will undertake actions to reduce or cope with the effects of invasive species on the marine environment*, will be ≥7 on 0–10 scale. (ii) If pre course response is <7, effect size (Cohen's *d*) will show a medium or greater positive effect (≥0.8)
Indicator	Pre-survey to post-survey responses	Pre-survey to post-survey responses	Pre-survey to post-survey responses	Pre-survey to post-survey responses	Pre-survey to post-survey responses	Pre-survey to post-survey responses

TABLE 4 | Theory of Change model for the educational videos presented within workshops for school pupils (aged 11–15).

"**Rethinking plastic**" **educational video theory of change**	**Problem awareness/knowledge**	**Knowledge**	**Attitude**	**Attitude—belief in benefit from own action (self-efficacy)**	**Interpersonal communication/social norm**	**Behavior change**
Theory of Change: AIM	Following the intervention participants will be aware (informed) of the issue or problem in the key story	Following the intervention knowledge about the issue (key story) will have increased	Following the intervention attitude toward the issue would have changed, and change in behavior supported	Following the intervention participants feel the response action will be effective (there will be a benefit)	Following the intervention participants will communicate about the issue or topic with friends, family and at work or school	Behavior adopted or intention expressed
Measurable objective	(i) After the course, mean response of participants who watch the video and take part in activities, to the statements: "*I have good knowledge about how microplastics effect native marine life and how microplastics may affect human health?"* (0–10 scale) will be ≥7. (ii) If mean pre course response is <7, effect size (Cohen's *d*) will show a medium or greater positive effect (≥0.8)	After the course, ≥75% of course participants will correctly answer the ocean literacy knowledge quiz question (time in years a plastic bottle takes to degrade in the sea)	(i) After the course mean response of participants to the question, "*how worried are you about the problems microplastics in the sea might cause?"* (0–10 scale) will be ≥7. (ii) If mean pre course response is <7, effect size (Cohen's *d*) will show a medium or greater positive effect (≥0.8)	(i) After the course, mean response of participants to the statement: "*I believe there will be a benefit to the health of the sea and people's health if I stop using products containing micro-plastics,"* (0–10 scale) will be ≥7. (ii) If mean pre course response is <7, effect size (Cohen's *d*) will show a medium or greater positive effect (≥0.8)	(i) After the course, mean response of participants to the statement "*How often do you talk about ways of helping to reduce the problems microplastics may cause in the sea with your family, friends, colleagues or teachers"* (0–10 scale) will be ≥7. (ii) If mean pre course response is <7, effect size (Cohen's *d*) will show a medium or greater positive effect (≥0.8)	(i) After the course, mean response of participants will be ≥7 for at least 2 intended behavior options to "*help reduce the effects of micro-plastics on the marine environment in the future."* (ii) If mean pre course response is <7 for the options, effect size (Cohen's *d*) will show a medium or greater positive effect (≥0.8) for at least 2 options
Indicator	Pre-survey to post-survey responses	Pre-survey to post-survey responses	Pre-survey to post-survey responses	Pre-survey to post-survey responses	Pre-survey to post-survey responses	Pre-survey to post-survey responses

language to make it more suitable for the younger sample. The questionnaire was completed with assistance of teachers and course leaders during an introduction session (pre) and again at the following day, after viewing the film (post). The questionnaire took about 10 min to complete.

The pre-course questionnaire included eleven questions designed to assess participants' awareness of the issue of microplastics entering the sea, general concern for damage to the environment, knowledge, perceived understanding, concern about effects of microplastics on marine life, belief and values, communication about the issue, and self-reported behaviors in relation to specific actions to help reduce or cope with the impacts of microplastics on the marine environment and human welfare. Further questions were designed to assess factors relating to participants' age, location, pre-existing concern for marine environmental issues and feedback on sources of information on environmental issues.

The post-course questionnaire included the same questions. Present tense was changed to future tense in relation to behavior questions to assess participants' intended behavior after completing the workshop.

Analysis

Analysis within both studies used the same approach, to test the effectiveness of the intervention on the participants in each case study example. Mean responses of the participants (on a scale of 0–10) in relation to questions associated with each objective in the Theory of Change model were calculated for pre and post survey responses (**Tables 3**, **4**). To test significance of changes between pre and post survey responses, paired samples t-tests were calculated and significance defined with Bonferroni correction such that only comparisons with $p < 0.005$ are interpreted as significant. Effect size Cohen's d was reported, calculated by taking the difference between the two means and dividing by the pooled standard deviation (i.e., the root mean square of the two SDs). Cohen's d accounts for sample size, and so provided a suitable test for effect size of changes between pre and post responses, for the limited number of respondents in the pilot studies. Here, 0.20 is considered a small effect, 0.50 is medium, 0.80 is large, and >1.20 is very large effect. Where effect size was high, greater confidence could be provided in significant associations identified by t-tests, even with smaller sample size. The extent to which predictors of behavior (level of knowledge, agreement with attitude statements and, for study 1 participants level of confidence and self-efficacy, in post surveys) predicted participants intended frequency of undertaking ocean literate behavior in post surveys were assessed using linear regression calculations to provide r^2 values to assess relationships.

RESULTS

Study 1

Objectives in Theory of Change

Pre and post survey responses were used to assess if objectives within the Theory of Change for the "Sustainable Seafaring" course had been met (**Table 5**, **Figure 1**). Knowledge, attitude and intended indicator objectives were met, as they increased significantly between pre and post survey responses, even with Bonferroni corrections, providing confidence that there is only an exceptionally small opportunity the difference could have occurred by chance ($p \leq 0.005$). After completing the course, participants reported they were significantly more informed about invasive species $t_{(16)} = 8.14$, $p < 0.001$, $d = 2.5$, and had greater knowledge of the effects of invasive species on the marine environment $t_{(16)} = 6.06$, $p < 0.001$, $d = 1.5$, and human welfare $t_{(16)} = -6.23$, $p < 0.001$, $d = 1.72$. Significant changes were also observed in participant's attitudes. Their concern about the effects of invasive species on native marine life increased $t_{(16)} = 6.94$, $p < 0.001$, $d = 1.8$, as did their belief that there would be a benefit from treatment of ballast water $t_{(16)} = 4.56$, $p < 0.001$, $d = 1.4$.

Belief that there would be a benefit from treatment of ballast water received almost complete mean agreement [mean agreement = 9 (SE ± 0.2)], after the course. Participants agreement that, after the course, they felt capable that they can reduce the spread of invasive species through everyday actions as seafarers showed a small positive change $t_{(16)} = 1.32$, $p < 0.1$, $d = 0.4$. Self-reported frequency of communication with friends, family and colleagues about effective ways of helping to reduce or cope with the effects of invasive species showed a significant increase after the course $t_{(16)} = 2.34$, $p = 0.02$, $d = 0.5$.

After completing the course, the class, who were in their final months of training before entering the seafaring industry reported a strong intention to frequently undertake actions to reduce or cope with the effects of invasive species on the marine environment [mean response = 7.7 (SE ± 0.4) on 0 (not at all)-−10 (all the time) scale]. This represented a significant positive change from before reported frequency of actions undertaken prior to the course $t_{(16)} = 4.37$, $p < 0.001$, $d = 1.4$.

Students increased their perceptions of the effectiveness for all options to reduce or cope with the spread of invasive species. Before the course, perceived effectiveness was moderately high for the options involving, (i), "*crew to undertake best practice in operation of ballast water treatment,*" (ii), "*ships to have effective ballast water treatment systems,*" and d), "*research to investigate spread of invasive species and effectiveness of treatment systems*." The range of responses (on the 0–10 scale) for all three options pre course was between 7.0 and 7.2 and increased to between 8.2 and 8.6. Perceived effectiveness was moderate for the option, "*new ships to be constructed using ballast free designs.*" Following the course there was a significant increase in perceived effectiveness of construction of ballast free ships $t_{(16)} = 1.74$, $p < 0.05$, $d = 0.8$. Effect size (Cohens d) showed a large positive effect between pre and post course surveys for all options ($d = \geq 0.8$). Despite the small sample size, large effect sizes (Cohens d) support the significant increase observed in the t-test result for these intended behaviors, as well as other predictors of behavior change, to undertake or support actions to reduce or cope with the effects of invasive species on the marine environment.

Pre-existing Environmental Connectedness

Before the course, the mean self-reported awareness of environmental issues, and concern about damage to the

TABLE 5 | Summary of results of pre ad post surveys in relation to objectives within the "Sustainable Seafaring" course theory of change.

	Problem awareness	Knowledge	Attitude	Attitude – self efficacy	Interpersonal communication/social norm	Behavior
Objective	(i) After the course, mean response of shipping industry professionals (participants) to the question "*how informed about the effects of invasive species on the marine environment?"* (0–10 scale) will be ≥7. (ii) If pre course response is <7, effect size (Cohen's *d*) will show a medium or greater positive effect (≥0.8)	After the course, (i) mean agreement of participants to the statement "*I have good knowledge about how invasive species effect native marine life and how invasive species may affect human welfare."* will be ≥7. (ii) If pre course response is <7, effect size (Cohen's *d*) will show a medium or greater positive effect (≥0.8). (iii) ≥75% of respondents will correctly answer the knowledge quiz question after the course	After the course, (i) mean response of participants to the question "*how concerned are you about the effects of invasive species on native marine life?"* (0–10 scale) will be ≥7. (ii) If pre course response is <7 effect size (Cohen's *d*) will show a medium or greater positive effect (≥0.8). (iii) Mean agreement of participants to the statement *"I believe it will be better for the ocean environment and marine life, if ballast water is treated'* (0–10 scale) will be ≥7. (iv) If pre course response is <7, effect size (Cohen's *d*) will show a medium or greater positive effect (≥0.8)	After the course, (i) mean agreement of participants to the statement, *"I feel capable that when I start to work as a seafarer, I can reduce the spread of invasive species through my everyday actions,"* (0–10 scale) will be ≥7. (ii) If pre course response is <7, effect size (Cohen's *d*) will show a medium or greater positive effect (≥0.8)	After the course, (i) mean response of participants to the statement, *"How often do you talk about effective means of helping to reduce or cope with the effects of invasive species with family, friends, colleagues or teachers,"* (0–10 scale) will be ≥7. (ii) If pre course response is <7, effect size (Cohen's *d*) will show a medium or greater positive effect (≥0.8)	After the course, (i) mean response of participants reporting that they *will undertake actions to reduce or cope with the effects of invasive species on the marine environment*, will be ≥7 on 0–10 scale. (ii) If pre course response is <7, effect size (Cohen's *d*) will show a medium or greater positive effect (≥0.8)
Result	(i), Mean response (post) = 8.4 (SE ± 0.3) (ii) Mean response (pre) = 4.7 (SE ± 1.2) Cohens *d* = 2.5	(i), Mean response post (environment) = 7.6 (SE ± 0.3) (welfare) = 7.7 (SE ± 0.3) (ii) Mean response pre (environment) = 4.7 (SE ± 0.6) Cohens *d* = 1.5, (welfare) = 4.9 (SE ± 0.5) Cohens *d* = 1.7. Correct answer = 88%	(i), Mean response post (concern) = 8.29 (SE ± 0.3) (belief) = 9 (SE ± 0.2) (ii) Mean response pre (concern) = 5.2 (SE ± 0.5) Cohens *d* = 1.8, (belief) = 6.8 (SE ± 0.5) Cohens *d* = 1.4	(i), Mean response (post) = 7.6 (SE ± 0.3) (ii) Mean response (pre) = 6.8 (SE ± 0.5) Cohens *d* = 0.4	(i), Mean response (post) = 5.4 (SE ± 0.7) (ii) Mean response (pre) = 4.0 (SE ± 0.7) Cohens *d* = 0.5	(i), Mean response (post) = 7.7 (SE ± 0.4) (ii) Mean response (pre) = 4.7 (SE ± 0.7) Cohens *d* = 1.4
Objective achieved? Yes/No	(i) Y, (ii) Y	(i) Y, (ii) Y, (iii) Y	(i) Y, (ii) Y, (iii) Y, (iv) Y	(i) Y, (ii) N	(i) N, (ii) N	(i) Y, (ii) Y

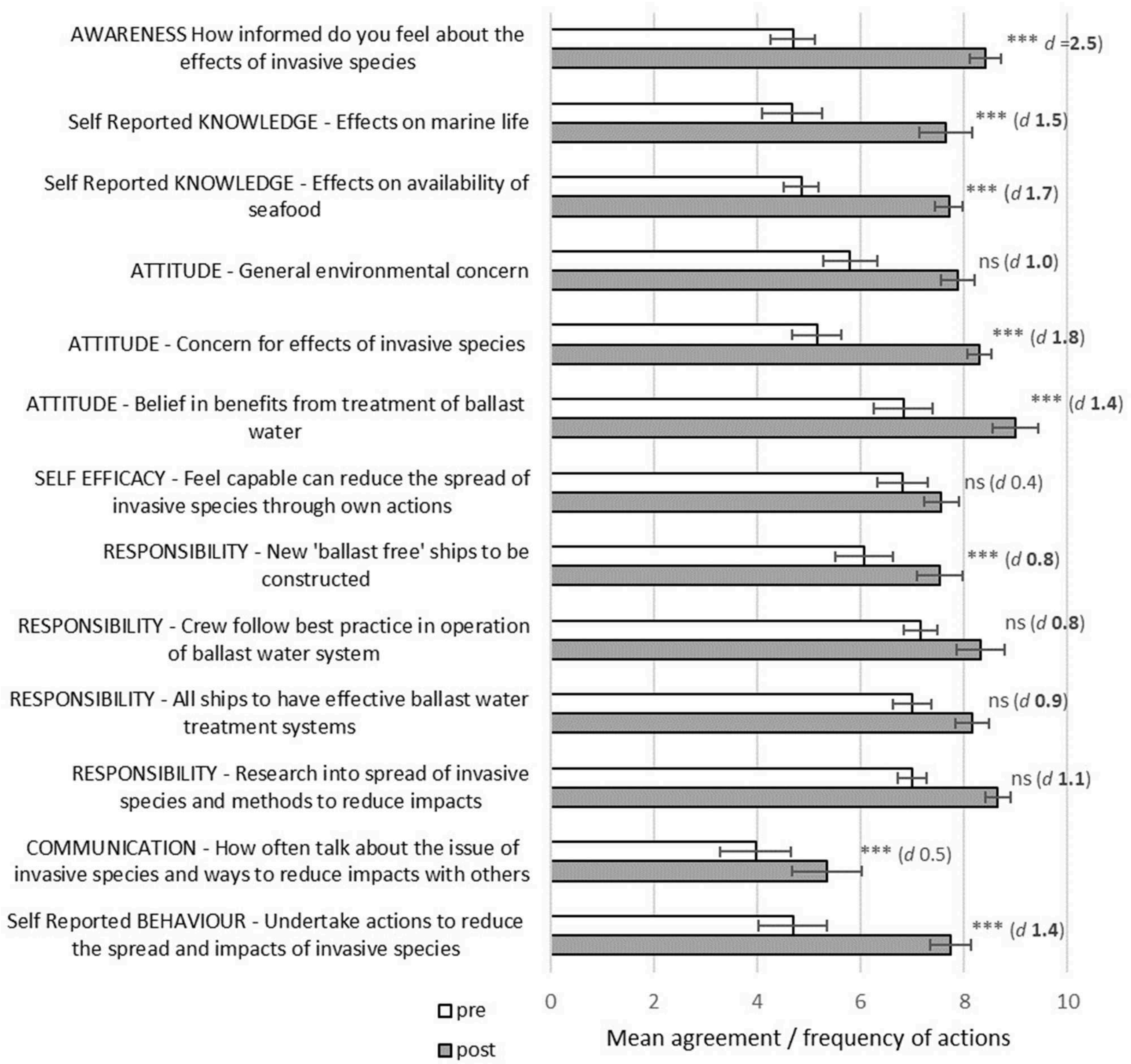

FIGURE 1 | Mean participant responses to pre and post surveys completed before and after participating in the "Sustainable Seafaring" course, significant differences ($p \leq 0.005$) between pre and post surveys are indicated by ***, effect size (Cohen's d) of medium or above are in bold (d = **#**).

natural environment was moderately high for the student group [mean 7.2 (SE ± 0.5) and mean 7.5 (SE ± 0.5), respectively]. Agreement with the statement "*I always think about how my actions effect the marine environment*" was moderate before the course (pre) (5.8 SE ± 0.6). Proportion of the student group expressing awareness, concern or reflection on the effect of actions on the marine environment, higher than a moderate level (>6), before the course, was 65% (aware), 75% (concern), 35% (reflection on effect of actions). All respondents lived between 0 and 1.8 kilometers from the coast.

Influence of Knowledge, Awareness, and Attitude Ocean Literacy Dimensions on Intended Behavior

For post course responses, the results of linear regression calculations (r^2 values) between each predictor of behavior change and student's level of intention to undertake actions showed weak relationships for all predictors of behavior change (**Table 6**). No significant relationship was present (**Table 6**). Low r^2 values in a range between 0 and 1, suggest a larger deviation of the sample data from the modeled "line of best fit." The value would be expected to be greater and thereby, data closer to the line of best fit, if one variable strongly predicted the

TABLE 6 | Linear regression calculations to assess extent to which predictors of behavior change (awareness, knowledge, attitude, self-efficacy and social norm) predict participants self-reported intended frequency of undertaking behaviors or actions to reduce the effects of invasive species on native marine life.

Ocean Literacy dimension, correlated with intended behavior (0–10)	Intended frequency of undertaking behaviors or actions (post intervention)		
	F	*P*	r^2
"Pre-existing pro-environmental attitude" *"I am concerned about damage to the natural environment"*	1.185	0.29	0.078
"Pre-existing pro-environmental attitude" "*I always think about how my actions affect the environment"*	2.165	0.16	0.126
"How informed" (0–10)	1.224	0.29	0.075
"Knowledge" (environment) (0–10)	1.380	0.26	0.084
"Knowledge" (human welfare) (0–10)	0.097	0.76	0.006
"Attitude" Concern (0–10)	0.131	0.72	0.009
"Attitude" Belief in benefits of action (0–10)	1.544	0.23	0.093
"Self-efficacy" Feel capable can reduce impact through own actions (0–10)	0.374	0.55	0.026
"Responsibility" Crew follow best practice (0–10)	0.011	0.92	0.001
"Communication" with others about impacts (0–10)	0.168	0.17	0.123

other. It is important to consider that the small sample size may limit effectiveness of this analysis and results should be interpreted with caution. A greater number of respondent's for pre and post surveys would provide greater confidence in the association between the data and line of best fit generated by the linear model. There may also be differences between each individual respondent's motivation for their intended frequency of undertaking behaviors. It must be considered that there may be a more complex interaction between level of knowledge, level of attitude and considerations such as socially expected behaviors that influence behavior intention, than are expressed in the results of the linear regression calculations.

Study 2

Objectives in Theory of Change

As with the seafaring course, pre and post survey responses were used to assess if objectives within the Theory of Change for the "Rethinking plastic" film presented within the NMA activities, in Plymouth, UK and showings in Tulcea, Romania had been met (**Table 7**, **Figure 1**). All indicators for each objective were met, apart from 26% of participants still got the quiz question wrong (on number of years a plastic bottle takes to degrade in the sea), and although the level students reported talking about the issue with other increased between pre and post surveys, frequency of communicating about the issue was still moderate. For all other indicators of objectives, indicator objectives were met. There were significant differences between pre and post survey responses, even with Bonferroni corrections, providing confidence that there is only an exceptionally small opportunity the difference could have occurred by chance ($p \leq 0.005$).

After viewing the film and participating in the activities, participants self-reported knowledge about (i), how microplastics effect marine life and (ii), how microplastics may affect human health, had significantly increased [marine life $t_{(15)} = 4.7$, $p < 0.005$, $d = 5.99$, human welfare $t_{(15)} = 3.49$, $p < 0.005$, $d = 4.6$] (**Figure 1**). Before the course 71% of participants answered the knowledge question "How long does a plastic bottle take to degrade in the ocean?" After the course 75% of participants answered the question correctly.

Participants pre-existing concern for damage to the natural environment and concern for the effects of microplastics on marine life was high at the start of the study (natural environment, mean 8.86 SE ± 0.18, effects of microplastics, mean 8.36 SE ± 0.21) (**Figure 2**). Concern remained high or showed a small increase after the viewing the film, a small to moderate positive effect size occurred for concern for effects of microplastics [concern about damage to the environment $t_{(32)} = 0.47$, $p = 0.64$, $d = 0.07$, concern about effects of microplastics $t_{(31)} = 1.08$, $p = 0.29$, $d = 0.24$]. Participant's level of agreement with the statement that, "I believe there will be a benefit to the health of the sea and people's health if I stop using products containing micro-plastics," was also high before viewing the film (mean 8.42 SE ± 0.25) and showed a small increase after the event (mean 8.52 SE ± 0.32) [$t_{(30)} = 1.01$, $p = 0.32$, $d = 0.06$] (**Figure 2**).

Self-reported frequency of communication with friends, family and colleagues about, "ways of helping to reduce the problems microplastics may cause in the sea." showed an increase after the course $t_{(32)} = 1.09$, $p = 0.28$, $d = 0.19$ (**Figure 2**).

After completing the course, the participants who were attending the event from across the UK, reported a strong intention to frequently undertake all actions to: "help reduce the effects of micro-plastics on the marine environment in the future." Self-reported frequency of undertaking the action: "separating plastics for recycling" was already high (mean) in the pre intervention survey, and there was still a small increase in frequency participants intended to undertake this action in the future $t_{(30)} = 2.35$, $p = 0.02$, $d = 0.5$ (**Figure 2**). Before the event, participants reported a moderate frequency of "looking for products that use packaging that can be recycled" (Mean 6.3 SE ± 0.43) and after the event a greater frequency of undertaking the action was intended (mean 7.4 SE ± 0.43) although with Bonferroni correction the change was not significant $t_{(30)} = 2.85$, $p = 0.007$, $d = 0.33$ (**Figure 2**). Significant increases occurred in frequency participants reported they would undertake the actions "looking for products that don't contain microplastics," and, "supporting shops that don't sell products containing microplastics" [look for products $t_{(30)} = 4.92$, $p = < 0.005$, $d = 0.8$, supporting shops, $t_{(30)} = 4.59$, $p = < 0.005$, $d = 0.48$] (**Figure 2**). Despite moderate sample sizes, medium to large effect sizes (Cohens *d*) support the significant increase observed in the t-test result for these intended behaviors to reduce use of products containing microplastics.

Cronbach's alpha values calculated across responses to current frequency of behaviors and intended behavior

TABLE 7 | Summary of results of pre and post surveys in relation to objectives in the theory of change related to participants' viewing the "Rethinking Plastic" film.

	Problem awareness/knowledge	Knowledge	Attitude (concern)	Attitude—[belief in benefit from own action (self-efficacy)]	Interpersonal communication/social norm	Behavior change
Objective	(i) After the course, mean response of participants who watch the video and take part in activities, to the statements: *"I have good knowledge about how microplastics effect native marine life and how microplastics may affect human health?"* (0–10 scale) will be ≥7. (ii) If mean pre course response is <7, effect size (Cohen's *d*) will show a medium or greater positive effect (≥0.8)	After the course, ≥75% of course participants will correctly answer the ocean literacy knowledge quiz question (time in years a plastic bottle takes to degrade in the sea)	(i) After the course mean response of participants to the question, *"how worried are you about the problems microplastics in the sea might cause?"* (0–10 scale) will be ≥7. (ii) If mean pre course response is <7, effect size (Cohen's *d*) will show a medium or greater positive effect (≥0.8)	(i) After the course, mean response of participants to the statement: *"I believe there will be a benefit to the health of the sea and people's health if I stop using products containing micro-plastics,"* (0–10 scale) will be ≥7. (ii) If mean pre course response is <7, effect size (Cohen's *d*) will show a medium or greater positive effect (≥0.8)	(i) After the course, mean response of participants to the statement *"How often do you talk about ways of helping to reduce the problems microplastics may cause in the sea with your family, friends, colleagues or teachers"* (0–10 scale) will be ≥7. (ii) If mean pre course response is <7, effect size (Cohen's *d*) will show a medium or greater positive effect (≥0.8)	(i) After the course, mean response of participants will be ≥7 for at least 2 intended behavior options to *"help reduce the effects of micro-plastics on the marine environment in the future."* (ii) If mean pre course response is <7 for the options, effect size (Cohen's *d*) will show a medium or greater positive effect (≥0.8) for at least 2 options
Result	(i), Mean response post (environment) = 7.97 (SE ± 0.29) (welfare) = 7.54 (SE ± 0.34) (ii) Environment Cohens *d* = 1.05, welfare Cohens *d* = 0.95	Correct answer (post) = 74%	(i), Mean response (post) = 8.57 (SE ± 0.28) (ii) Mean response (pre) = 8.36 (SE ± 0.21) Cohens *d* = 0.24	(i), Mean response (post) = 8.52 (SE ± 0.32) (ii) Mean response (pre) = 8.42 (SE ± 0.25) Cohens *d* = 0.06	(i), Mean response (post) = 5.57 (SE ± 0.41) (ii) Mean response (pre) = 5.11 (SE ± 0.42) Cohens *d* = 0.19	(i), Mean response (post) = >7 for all behaviors (ii) Mean response (pre) = 5.69 across behavior options. Cohens *d* = >0.8 for 2 behavior options
Objective achieved? Yes/No	(i) Y, (ii) Y	(iv) N	(i) Y, (ii) Y (all ready >7)	(i) Y, (ii) Y (all ready >7)	(i) N, (ii) N	(i) Y, (ii) Y

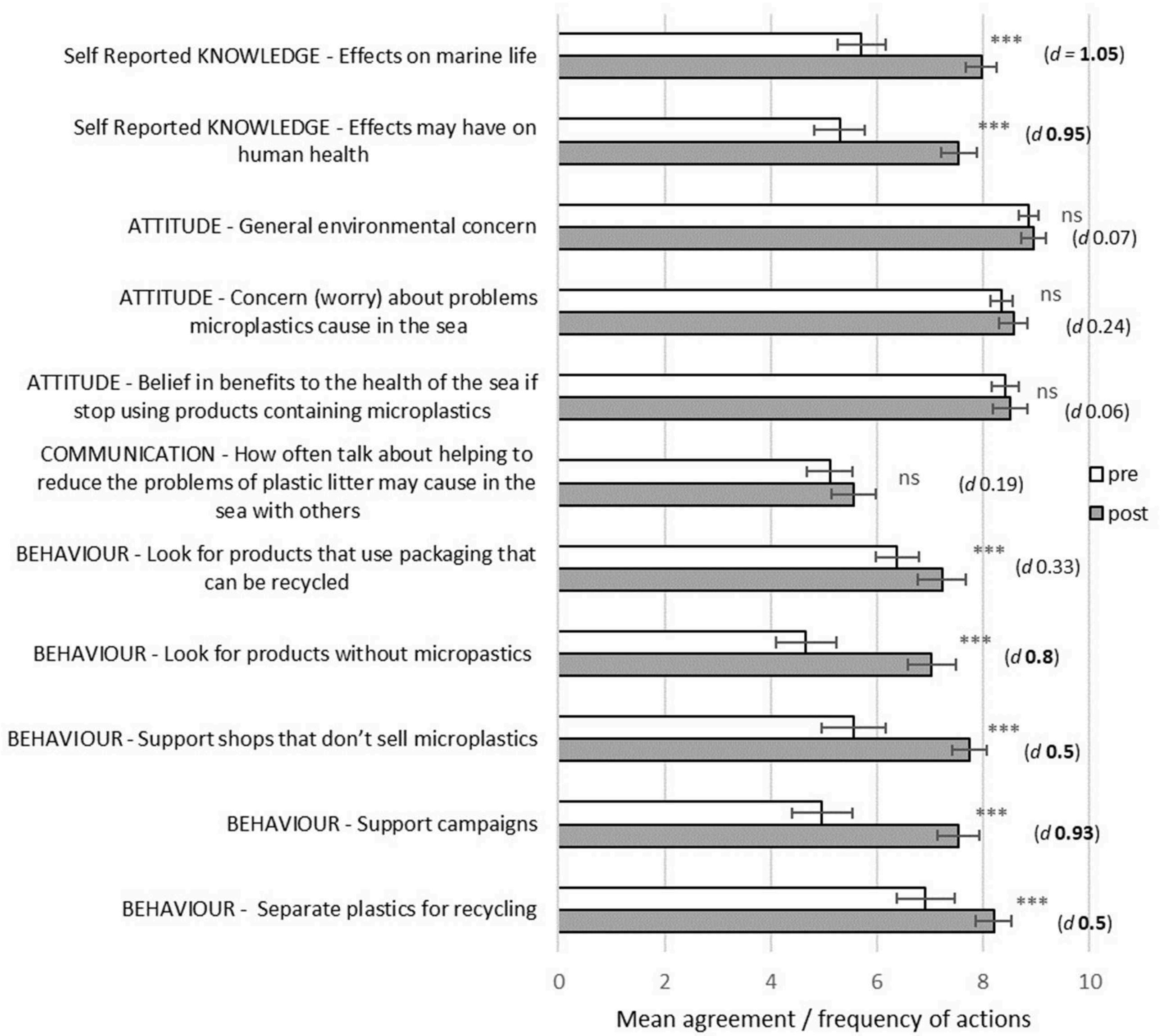

FIGURE 2 | Mean participant responses to pre and post surveys completed before and after viewing the "Rethinking plastic" film, significant differences ($p \leq 0.005$) between pre and post surveys are indicated by ***, effect size (Cohen's d) of medium or above are in bold ($d =$ **#**).

frequency of behaviors revealed acceptable internal reliability (current frequency responses 0.719, intended frequency responses, 0.759).

Pre-existing Environmental Connectedness

Participants level of pre-existing concern for damage to the natural environment was high at the start of the study (mean) and remained high $t_{(32)} = 0.47$, $p = 0.64$, $d = 0.07$ (**Figure 2**).

Influence of Knowledge, Awareness, and Attitude Ocean Literacy Dimensions on Intended Behavior

For post course responses, linear regression calculations provided a strong positive relationship between knowledge and attitude predictors of behavior change and intended behavior options specific to reducing use of microplastics. Participant's level of response to knowledge and attitude ocean literacy dimension questions were significant ($p \leq 0.005$) in predicting the level of participants reported level of intended frequency of undertaking the behavior "*look for products that do not contain microplastics*" (**Table 8**). Small or moderate relationships were present, for knowledge and attitude responses in relation to predicting participants reported level of intended frequency of undertaking other behavior options to "*reduce effects of microplastics in the sea*" (**Table 8**). Although relationships were not significant with Bonferroni correction ($p \leq 0.005$), moderately high r^2 values were returned in relation to participant's level of self-reported knowledge of effects on the environment as a predictor of intention to frequently support campaigns that aimed to reduce use of products with microplastics (r^2 0.473, $p = 0.007$). Small positive relationships was also identified for participants level of concern for the effects of microplastics on marine life and belief in benefits from taking action to reduce use of products with microplastics, as predictors of intended frequency to, "*support shops that don't sell microplastics*" and, "*support for campaigns to reduce use of microplastics*" (**Table 8**).

Differences Between Age Groups and Location

Greater mean support for intended frequency of undertaking behavior options in post surveys, was displayed by the older age group (16–18) in comparison to the younger age group (11–15), apart from for the intended behavior, "*separate plastics for recycling.*" No differences between groups were significant ($p \leq 0.005$) (**Table 9**).

Intended frequency of undertaking behavior options were higher for participants in Tulcea, Romania. However, no significant differences ($p \leq 0.005$) were observed between locations (Tulcea, Romania and Plymouth, UK) (**Table 10**).

DISCUSSION

Main Findings

For both pilot studies the pre and post surveys indicate an effective shift along the stages in the theory of change, from knowledge to intended behavior. Where indicators of objectives for a stage in the theory of change had not been met in responses to pre surveys, objectives were met in post survey responses, following interaction with the tool. As knowledge, attitude (concern and belief in benefit from taking personal action) and intended behavior objectives were met for both tools, the results suggest that the tools were effective at promoting ocean literacy and behavior change goals for the participants in the case study examples.

Following the ocean literacy initiatives, participants intended behavior, showed strong support for undertaking behaviors that would address the relevant environment issues, relating to human–ocean relationships. Increase in support for behaviors relating to the topics was significant between pre and post surveys, with large positive effect sizes for each initiative. Intended frequency of undertaking behaviors, not actual objective behavior was collected. Thereby, the consideration of the predictors of behavior change, identified by Klöckner (2013), are likely to be as influential in assessing the effectiveness of the ocean literacy initiatives as relying on self-reported behavior intention alone. Increases in both pilot studies, in participant's knowledge of effects of human activities on the ocean, and the resulting effects on human well-being, as well as participant's level of concern for those effects and belief that action needs to be taken, also provide evidence of effectiveness of the initiatives.

The pilot studies demonstrate that the application of predictors of behavior change, as indicators within a theory of change framework, provides a means to monitor achievement of objectives in relation to ocean literacy, identified within the United Nations (2018) revised roadmap for the "decade of ocean science for sustainable development." United Nations (2018) considered that, "*increased awareness and ocean literacy will be instrumental in triggering behavioural changes, such as adaptation of lifestyles, joining non-government organisations (NGOs), choosing ocean-affiliated professions*" (United Nations, 2018). In particular, for the major target audience (school children) and professional stakeholders, the pilot studies demonstrate the potential to assess the effectiveness of ocean literacy programmes to trigger behavior change, such as lifestyle decisions or supporting campaigns or NGOs. The framework tested in the pilot studies, therefore, provides a means of assessing effectiveness of ocean literacy programmes on target audiences.

Theory of Change—Intended Behavior and Predictors of Behavior Change

Intentions ("*I will do this*"), and perceived behavioral control ("*It is up to me whether I do this rather than other people or contextual factors*") are reviewed by Klöckner (2013) to both be in the category of "best predictors of behavior change," based on review of environmental psychology literature. These predictors of behavior change occur in the Theory of Change as the behavior change objective, and one of two attitude objectives [participant's "belief there is a benefit if I (they) undertake the action (an action relating to the behavior change objectives")]. Intended behavior has been shown to correspond with self-reported behavior in studies that have followed up with participants, but to show much less correspondence with objectively recorded behavior, such as observed behavior (Eccles et al., 2006). The combination of increases in all objectives for each predictor of behavior change, not just intended behavior change, provides greater confidence in the effectiveness of the initiatives. These findings are important to consider for ocean literacy initiatives and have been shown in relation to research into pro-environmental behavior change.

Multiple influencing factors are recognized to lead to pro-environmental behaviors by industry actors. A study of bait shop owners engagement in outreach activities to promote behaviors to reduce spread of invasive species displayed level of engagement depended on a combination of predisposing factors (Howell et al., 2014). High level of intention to engage in activities resulted in high level of actual engagement. However, results of a path model, investigating predictors of actual behavior, revealed intention to undertake the behavior did not solely account for actual undertaking of the behavior (Howell et al., 2014). High level of concern for the consequences (attitude), pressure from social networks (communication/social norm), perceived behavioral control and self-efficacy also had a significant effect on actual engagement with activities (Howell et al., 2014). In the results from the "Sustainable Seafaring" course we present here, the combination of objectives being met in addition to intended behavior are of great importance. Knowledge, attitude (concern for consequences and belief in benefits of taking action) and communication dimension objectives are met as well as the intended behavior objective, providing greater confidence that the behavior change goals will be achieved.

Multiple factors, including a significant increase in knowledge, supportive attitude, and significant increase in intended behavior suggests interaction of school students with the ocean literacy film "Rethinking Plastic" met behavior change objectives. As

TABLE 8 | Regression calculations to assess extent to which predictors of behavior change (awareness, knowledge, attitude, self-efficacy and social norm) predict participants self-reported intended frequency of undertaking behaviors or actions to reduce the effects of microplastics on marine life.

Ocean literacy dimension, correlated with intended behavior (0–10)	Knowledge (environment)			Attitude (concern effects)			Attitude (belief benefits)		
	F	*P*	r^2	*F*	*P*	r^2	*F*	*P*	r^2
"Look for products that don't contain microplastics"	16.984	<0.0005***	0.369	20.52	<0.0005***	0.414	24.3	<0.0005***	0.456
"Support shops that's don't sell microplastics"	6.96	0.013	0.193	6.47	0.017	0.182	7.59	0.01	0.208
"Support campaigns (0–10)"	8.36	0.007	0.473	8.24	0.008	0.221	4.64	0.04	0.138

***Indicate significant results ($p \leq 0.005$).

TABLE 9 | Mean intended frequency of each age group to undertake behavior options in the future, including Welch's *t*-test of difference between groups.

Behavior or action	Mean response (post) (11–15 age category)	Mean response (post) (16–18 age category)	Welch's *t*-test
Look for products that use recycled packaging	7.16 SE ± 0.58	7.9 SE ± 0.5	$t_{(27)}$ 0.96, $p = 0.34$
Look for products that do not contain microplastics	6.83 SE ± 0.63	7.75 SE ± 0.59	$t_{(25)}$ 1.04, $p = 0.31$
Support shops and brands that don't sell products containing microplastics	7.3 SE ± 0.46	8.5 SE ± 0.4	$t_{(27)}$ 1.95, $p = 0.06$
Support campaigns to ban the sale or use of microplastics in products	7.07 SE ± 0.55	8.5 SE ± 0.5	$t_{(27)}$ 1.92, $p = 0.07$
Separate plastics for recycling	8.26 SE ± 0.45	7.7 SE ± 0.58	$t_{(20)}$ 0.77, $p = 0.45$

discussed, intention to complete an action, when combined with attitudes supporting the behavior, is more likely to result in an action being undertaken (Klöckner, 2013; Howell et al., 2014). In the case of the school students, where mean levels of concern for consequences and belief in a benefit from taking personal action were already high, the information provided by the film its self on the details of the effects of microplastic pollution, and the actions that could be taken appears important. After viewing the film there was a significant increase in self-reported knowledge (of effects of microplastics on marine life and (potential) consequences for human health). There were also significant increases in intention to undertake behavior options that specifically reduce use of products containing microplastics. Regression analysis found level of knowledge was a significant predictor, as well as level of attitudes of concern and belief in benefits from personal action, in predicting intended frequency to "*look for products that do not contain microplastics.*" Actions to actively reduce microplastic use appeared to be relatively new behavior options to the students. Average frequency of undertaking behavior options that were likely to already be available to them before viewing the film, such as separating plastics for recycling, was already high. In comments replying to "where did you hear about these options" influence from school, wildlife clubs, T.V. and parent's behavior were mentioned in before studies and "here at the (national marine) aquarium" was increasingly mentioned after viewing the film. The higher reported and intended frequency in pre and post surveys by younger school students (11–15) to undertake the action "separate plastics for recycling may represent that this is a more commonly adopted behavior in households." Intended frequency of undertaking newer behaviors, directed at reducing or eliminating use of products containing microplastics was greater for the older school students (16–18). Pre-existing concern for the natural environment and concern for the impacts of microplastics on the marine environment were greater for the older school students and may suggest this difference, as well as understanding of terminology such as microplastics.

Ocean literacy initiatives around marine litter have previously been shown to influence pro-environmental behavior in school students. Younger school students reported performing more waste reduction behaviors following interaction with a marine litter initiative (Hartley et al., 2015). Results suggested the initiative had also boosted understanding of the causes and impacts of marine litter. The findings we present, support this, and although self-reported behavior post interaction was not collected in the surveys we report, all objectives for predictors of behavior change were met, apart from for "communication."

Although predictors of behavior change identified by Klöckner (2013) were from reviewed studies involving adults, they reflect central concepts in children's environmental education. Effectiveness of environmental education has been reviewed by Rickinson (2001) to be supported by six nodes, most recognized were students' (i) environmental knowledge (ii) environmental attitudes and behaviors, and (iii) environmental learning outcomes, while three were regarded as emerging: students' (i) perceptions of nature, (ii) experiences of learning, and (iii) influences on adults. As an education tool, the survey results, suggest the "Rethinking Plastic" film met objectives relating to the three most recognized nodes.

TABLE 10 | Mean intended frequency reported by participants at each location, to undertake behavior options in the future, including Welch's *t*-test of difference between groups.

Behavior or action	Mean response (respondents in Plymouth, UK)	Mean response (respondents in Tulcea, Romania)	Welch's *t*-test
Look for products that use recycled packaging	6.89 SE ± 0.72	7.93 SE ± 0.42	$t_{(24)}$ 1.25, $p = 0.22$
Look for products that do not contain microplastics	7.03 SE ± 0.75	7.23 SE ± 0.58	$t_{(28)}$ 0.21, $p = 0.83$
Support shops and brands that don't sell products containing microplastics	7.28 SE ± 0.58	8.13 SE ± 0.36	$t_{(25)}$ 1.25, $p = 0.22$
Support campaigns to ban the sale or use of microplastics in products	7.0 SE ± 0.65	8.1 SE ± 0.51	$t_{(28)}$ 1.33, $p = 0.19$
Separate plastics for recycling	8.0 SE ± 0.56	8.17 SE ± 0.45	$t_{(28)}$ 0.23, $p = 0.82$

Self-reported frequency of communication did not meet the objectives for either study. However, there was small increase in both studies which is likely to have a small multiplier effect, in cases where participants are likely to share information they have learnt and promote intended behaviors. For the school student group, this small increase may be very effective in reaching multipliers. Influences on adults (or "pester power") from young people is highlighted by Hartley et al. (2015) as being a recognized means of influencing family members, peers and the wider community, long identified by marketing and consumer research (Wilson and Wood, 2004; Flurry and Burns, 2005). Although the association for marine litter related behaviors has not been tested, such relationships have been show in wider conservation topics. For instance, greater awareness and knowledge of parents has been related to children's environmental education in relation to other environmental education topics, such as importance of wetlands (Damerell et al., 2013).

The small increase in reported frequency of communication on the topic may be related to post interaction surveys only being undertaken within 24 h of school students interacting with the "Rethinking Plastic" film and engineering college students interacting with the "Sustainable Seafaring" course. This provided limited time for participants to actually discuss the topic with friends, family and colleagues. Completing, or following up the after survey, even up to a week or month after the event may have changed this result, and also allowed for reporting on change in reported as well as intended frequency of undertaking each behavior.

Improving Experimental Approaches

The assessment of effectiveness of behavior change objectives would benefit from follow-up surveys to record self-reported behavior in the months after interaction with the initiative. This would also allow researchers to assess if the behavior was also becoming habitual, a key predictor of long-term behavior change (Klöckner, 2013). As surveys were completed in the presence of course tutors or educators, there may be a risk of social desirability bias. The behavior options have been demonstrated by the film or course and support of these may be felt to be desired by the course leaders or educators, as well as being the socially expected response (Brenner and DeLamater, 2016).

To fully assess long term accomplishment of behavior change objectives would require additional objective indicator data, such as observational data. As recognized in the review work by Klöckner (2013), understanding change in an individual's habits (behaviors that have become automatized through repetition), is also amongst the best direct predictors of behavior change (**Table 1**). Examples of methods that could be applied, include observing individual's behavior in supermarkets in relation to purchasing choice, as applied for plastic bag use by Jakovcevic et al. (2014), or frequency of undertaking a behavior such as littering in parks (Schultz et al., 2013). For participants of an ocean literacy initiative with an associated app or social media site, frequency of visits to the social media site or of accessing information resources on an app within smart phones can be undertaken (Ernsting et al., 2017; Dempsey et al., 2018).

It would also be beneficial to compare the treatment group to a control group who do not interact with the ocean literacy intervention. As Pahl and Wyles (2017) discuss, this would allow identification of other external factors which could account for the any change identified over time. It would also add to the assessment if participant's from broader backgrounds were included, as participants of existing pilot studies showed moderate to high pre-existing concern for damage to the marine environment, although this could not necessarily be ascertained before the pilot study. A "*rigorous ocean literacy programme of activities*" intended to approach all actors, from school age children to governments, as identified by United Nations (2018), would need to be implemented across participants with different levels of pre-existing pro-environmental attitudes, and similarly the assessment be conducted across all groups.

Follow up surveys would also benefit from addressing the barriers and enabling factors for adoption of new behaviors. Understanding the barriers to adoption of behavior would potentially aid addressing the limited increase observed in self-efficacy between pre and post surveys by young professionals (seafarers) sample. Self-efficacy has been shown to be an important area to considering addressing ocean literacy of professionals. Actual adoption of climate change initiatives by farmers was shown to depend on perceived capacity and self-efficacy, while attitudes such as concern and belief in benefits from action were only associated with intended not actual adoption (Niles et al., 2016). Participants of the seafaring course raised the point in workshop sessions, that they will be junior officers when they start work on board ships and will have to follow orders or protocol set out by superior officers or the ship owners. Addressing ocean literacy around industry specific topics, would appear to benefit from targeting actors involved across the industry, including, experienced officers and ship owners as well as young career professionals.

CONCLUSIONS

For both studies, pre and post surveys provided a means of assessing indicators of effective shifts along the stages in a Theory of Change, from knowledge to intended behavior, for participants encountering an ocean literacy initiative. As knowledge, attitude, such as concern and belief in benefit from taking personal action, and intended behavior objectives were met tools, and not just intended behavior or even just awareness, the approach provides greater confidence that the ocean literacy initiative has effected behavior change objectives. The approach, thereby, benefits from taking into account multiple predictors of behavior change.

The results display the effectiveness of applying the pre and post survey approach, within a theory of change model where each stages identifies each predictor of behavior change. The results of surveys demonstrated the effectiveness of tools on small sample groups of different actors. Although, with such small sample sizes, conclusions for effectiveness of the tools across a population level cannot be made, the approach is beneficial in building evidence of effectiveness. The approach identified the pre-existing pro-environmental attitudes held by the school students attending the National Marine Aquarium event. The survey approach was able to demonstrate the benefit of providing specific knowledge on the cause and effect of microplastics entering the sea and the consequences for marine life and human health. Displaying specific actions the viewers could take to reduce the problem appears important at providing knowledge on actions and their benefits that could be taken, encouraging the students pre-existing attitudes to support actions.

The approach, demonstrated the effectiveness of a 2 day course, for early career seafarers (engineer and deck officers), dedicated to wider ocean literacy knowledge about the ocean environment and the impacts of invasive non-native species. Comparison of pre and post survey results was able to demonstrate the effectiveness of the course in raising levels of knowledge, and also attitudes of greater concern and belief in benefit from action, and to undertake intended behavior. The approach identified some limitations in capability of early career professionals to change industry behavior, and that self-efficacy was limited by decisions of superior officers and ship owners.

The study supports earlier research, that identifies that ocean literacy initiatives (and wider environmental education), when tailored to relevant issues and actors, increases knowledge and attitudes of greater concern and belief that personal action will bring benefits. Future application of pre and post survey techniques to assess change in predictors of behavior change in relation to ocean literacy interventions would benefit from also undertaking longer term assessment of indicators, including participant's self-reported behavior, and also collecting objective observational data. The study also identified that approaching all actors that can influence a human-ocean relationship will bring wider benefits. Ultimately the young career seafarers identified that their action may be beneficial. However, these respondents also identified that change in attitude and behavior of shipping companies and governments to support actions is required for problems to be fully addressed.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of Research Ethics Policy of University of Plymouth Science and Engineering Faculty Research Ethics and Integrity Committee with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the University of Plymouth Science and Engineering Faculty Research Ethics and Integrity Committee.

AUTHOR CONTRIBUTIONS

MA, SP, and GG contributed to the design and implementation of the study. SF contributed to report written content. MA analyzed the data and prepared the report.

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Exploring Our Oceans: Using the Global Classroom to Develop Ocean Literacy

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Developing the ocean literacy of individuals of all ages from all countries, cultures, and economic backgrounds is essential to inform choices for sustainable living in the future, but how we reach and represent diverse voices is a challenge. Massive Open Online Courses (MOOCs) offer a possible tool to achieve this goal, as they can potentially reach large numbers of people including those from lower and middle income regions. The number of MOOCs themed around ocean science and/or literacy is growing rapidly, and here we share experience of developing and delivering a MOOC entitled "Exploring Our Oceans," which has run ten times in the past 4 years with around 40,000 participants worldwide. The "Exploring Our Oceans" MOOC incorporates a blend of online teaching techniques grounded in both instructivist and constructivist theories, thereby emphasizing contributions from a global community of learners and encouraging individual, independent action in relation to ocean citizenship. The impacts of this MOOC include evidence of changed awareness and attitudes to ocean issues; increased applications and participation in undergraduate and postgraduate programs; development of communication and outreach skills in the postgraduate community and partnership building with Nelson Mandela University, South Africa. These impacts, and vignettes of learner experiences in the course, are discussed in the context of the effectiveness of MOOCs in developing global ocean literacy.

Keywords: ocean literacy, open education, MOOCs, online learning, distance learners

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BACKGROUND AND RATIONALE

Almost 2.4 billion people live within 100 km of the ocean globally and they interact directly with the ocean on a regular basis (United Nations Ocean Conference, 2017). A significant proportion of all our resources originate from the oceans and the sustainability of these supplies is intimately linked to decisions made by individuals and society that stem from ocean literacy, defined as an understanding of the interactive and mutual impact of humans, society and the ocean environment. The Marine Biological Association of the United Kingdom describes an ocean-literate individual as one who "Understands[ing] the importance of the ocean to humankind, can communicate about the ocean in a meaningful way, and is able to make informed and responsible decisions regarding the ocean and its resources." UNESCO defines ocean literacy as "the understanding of our influence on the ocean and the ocean's influence on us. Ocean literacy is a way not only to increase the awareness of the public about the ocean, but it is as an approach to encourage all citizens and stakeholders to have a more responsible and informed behavior toward the ocean and its resources.

It is not just knowledge about the state of the ocean but a deeper understanding of our individual and collective responsibilities to take care of the ocean."

The seven principles of ocean literacy (Ocean Literacy, 2013 and **Table 1**) are beginning to be used widely as a framework for development of an ocean-literate society. Ocean literacy leads to more informed participation in the discussion on the future of the oceans and more responsible and effective decision making (Fauville et al., 2018). Ocean literacy requires individuals to be empowered with knowledge and then inspired to act (McPherson, 2018 p. 20). These acts can involve communicating about the ocean in a meaningful way as well as making informed decisions about behavior changes at individual through to societal scales.

INTRODUCTION

Global learning formats such as massive open online courses (MOOCS) provide open access to information and increased interactions between researchers and global society (Visbeck, 2018) and thus have potential to reach large numbers of ocean literacy learners. Like many equivalent organizations, the University of Southampton has invested in online courses for a number of related reasons that include: enhancing on-campus delivery of innovative online experiences for students of all levels; promoting research and education strengths to a global audience; addressing accessibility and widening participation; internationalizing the student experience; offering lifelong and flexible learning; and fostering innovation and enhancement in the curriculum.

The University of Southampton has extensive institutional experience and expertise in the development and delivery of online education and since 2012 has been a partner with FutureLearn, one of the providers of MOOCs. Exploring Our Oceans is one of several courses that launched on the FutureLearn platform in 2014. The high-quality FutureLearn format provides a forum where learners and facilitators build a connected, global on-line community that not only links our geographically distinct campuses in the United Kingdom and Malaysia but our postgraduate facilitators and collaborators that are based around the globe in South Africa, United States or on ships in the middle of the ocean. These communities of learners are sustained long after the initial learning experience has ceased through adjunct activities such blogs (>300 reads per week), social media (∼1000 followers), or enrolment in campus based programs (see below).

The original design brief for the Exploring Our Oceans MOOC was to raise awareness of deep ocean environments and human impacts on them, and enable public engagement with the University of Southampton's specific research in this area. This contribution therefore summarizes evidence of outcomes for participants that are consistent with enhancing ocean literacy, shares our experience of creating and delivering Exploring Our Oceans, and discusses the potential of MOOCs as an addition to the toolkit for building global ocean literacy.

MOOC PEDAGOGIES

The term x-mooc (Downes, 2012) refers to massive open online courses delivered via dedicated platforms and which are based primarily on behaviorist learning theory and didactic methods (Rodriguez, 2012). Course materials mainly consist of short videos and online quizzes. Conversely, learning in c-moocs "results not from the transmission of information from an expert to novices, but from the sharing and flow of knowledge between participants" (Bates, 2015, paragraph 5.3.2.1). c-moocs can be distinguished from x-moocs by the following design features: learner autonomy, diversity, interactivity, and openness (Downes, 2014).

The Meltzoff et al. (2009) study of infant and machine learning highlighted social learning as a powerful learning tool. This work was subsequently cited as "a catalyst for the creation of FutureLearn" (Future Learn, 2018, p.7). The three unpinning principles of FutureLean pedagogy are telling stories, provoking conversation, and celebrating progress. There is a strong design emphasis on Conversation Theory, Active Learning and Social Learning. The underpinning pedagogies of the FutureLearn platform are naturally aligned to developing the ocean literacy skills. This relative newcomer to online learning platforms launched in late 2013 and has rapidly risen to a rating in the top six platforms, alongside originals such as Coursera and EdX.

However, other researchers caution that a binary view of design is less useful as greater numbers of these courses now incorporate features of both designs, and that MOOC pedagogies are more nuanced "[taking] account of . . .a micro level of individual course design" (Bayne and Ross, 2014).

METHODOLOGY: EXPLORING OUR OCEANS COURSE DESIGN

The course was originally built around six consecutive weeks of study, later revised to 4 weeks after four runs of the course. In each week, learners are expected to undertake approximately 3 h of activity to complete core course materials, and the content for each week is organized around a specific theme (e.g., mapping and exploration; physical and chemical oceanography; marine biodiversity). Whilst learners can engage with the subject matter in any order they choose, the course team's online facilitators provide focused discussion and interaction with each "live" week of the course from the launch date. Traditional instructional techniques include video to explain key concepts, and weekly formative quizzes. Video is used to show rather than tell learners, however, making use of on location filming and practical demonstrations. At the end of each week there is a reflection activity, where learners share what they have learned, not necessarily aligned to the specific learning objectives for the course. How learners discuss, construct and share new understanding is therefore more aligned to c-mooc design. **Table 1** summarizes the seven Principles of Ocean Literacy, 2013 and maps those principles to specific aspects of the course design.

Week One of the course introduces learners to the history of ocean exploration, including the 1872–1876 *HMS Challenger*

TABLE 1 | Exploring our Oceans course design mapped against Principles of Ocean Literacy.

Principle	Course content	Course learning objectives
The Earth has one big ocean with many rfeatures.	Weeks 1, 2, 4	Assess the distribution of salt in the ocean
The ocean and life in the ocean shape the features of Earth.	Week 2	Identify key controls on seawater composition and circulation
The ocean is a major influence on weather and climate.	Week 2	Understand the impact of deep ocean processes on global climate through ocean chemistry and physics
The ocean made the Earth habitable.	Weeks 2 and 3	Understand the impact of deep ocean processes on the Earth system
The ocean supports a great diversity of life and ecosystems.	Weeks 1, 3, 4	Interpret Collector's Curves to estimate numbers of undiscovered new species Explain some adaptations to life in deep ocean habitats
The ocean and humans are inextricably interconnected.	Weeks 1, 4	Reflect on personal effectiveness in limiting potential impacts on deep ocean environments
The ocean is largely unexplored.	Weeks 1, 3, 4	Evaluate the degree to which humans have mapped the deep ocean and its habitats

expedition, and the extent to which modern mapping techniques have been used to map the ocean floor. Learners are also invited to share their motivations for joining the course through a specific activity "What do the Oceans mean to you?" The aim of the activity is to identify similar and different viewpoints in the learner cohort, as well as a qualitative measure of impact (the same activity is repeated in the final week of the course). Learners share an image on a virtual notice board; over time these images have been collated into a mosaic which is shared with learners and the wider public. By asking learners to share their personal perspectives at the beginning of the course, the learning design puts the focus on individual journeys, a feature which is typical of c-moocs. This c-mooc feature is also used when the cohort explores a small section of the sea floor for themselves using an interactive map and research data from the academic team.

Week Two introduces learners to ocean circulation and seawater composition. The week's design and content strongly reflects an x-mooc model: that of traditional dissemination of information from lecturer to students. This is mostly due to the key concepts involved, such as movement of ocean currents, gyres, and tides, and chemical composition of seawater and residence time of the various components. We have augmented this delivery with activities designed to encourage learner to learner conversation. In doing so, these concepts become more relevant to learners on an individual level and therefore more likely to lead to deeper learning through personalization and grounding (Priniski et al., 2018). A particular example of this in the course design is a section about the composition of seawater. After watching a series of three instructional videos about why the sea is salty, where the salt comes from, and where it goes to, learners are asked to calculate the volume of salt in the ocean. This step of the activity is optional; offering a challenge for more confident learners. To engage with less confident learners and provide relevant, meaningful connections for the whole cohort, the next step provides the answer and invites learners to share their own comparisons, such as the one shared by Learner A, below.

Learner A

A red double decker bus in London is on average 4.8 m tall, this means the layer of salt that would be left on the sea floor if the water evaporated would be just over 12 and a half busses deep. . .this really gives me a great perspective of just how much that is!

Week Three focuses on biodiversity in the oceans, from microbes to large animals, and includes insights into the process of discovering and describing new species, and an overview of adaptations to deep-ocean environments. In this week the x-mooc course delivery is enhanced by directing learners to live online streaming of deep-sea remotely operated vehicle footage from research expeditions at sea, such as the NOAA Ocean Exploration Program and the Ocean Exploration Trust.

The final week of Exploring Our Oceans focuses on human impacts on the deep ocean, with content that has required the most updating on a regular basis, to keep pace with growing research into the potential environmental impacts of future deep-sea mining, and international environmental policy developments. In late 2015, the United Kingdom introduced charges for single use plastic bags, and public awareness of the environmental impacts of single use plastics has continued to grow, with further United Kingdom initiatives such bans on microbeads (2018) and planned bans on drinking straws, drinks stirrers and cotton buds (2019–2020). We incorporated new material on ocean plastics into this section in 2016, responding directly to learner interests and public debate. The final week of the course offers significant opportunity to engage with learners about their ocean literacy and personal effectiveness regarding ocean citizenship. We therefore have focused our thematic, qualitative analysis on learner comments posted during this final week of learning.

IMPACT/LEARNER CASE STUDIES

Since its inception in February 2014, Exploring our Oceans has run ten times. In total, more than 40,669 learners have signed up to the course in 183 of 195 countries around the world. Course sign-ups have translated into approximately over half (22,894) of those participants recording their engagement with course materials. The FutureLearn platform invites participants to indicate that they have completed steps in the course content, but recording the completion of a step is not required for participants to progress to other steps, and data on steps completed are therefore a minimum estimate of engagement with course materials. A significantly smaller proportion of participants recorded their completion of the course (12.5%), but this is still above average for MOOC completion rates of 5–10% (Chuang and Ho, 2016), and such metrics are controversial in terms of evaluating both learner and course success (Devlin, 2013; Jordan, 2014).

The impacts of the Exploring our Oceans MOOC include increased awareness of, and attitudes to, ocean issues; increased applications to undergraduate and postgraduate programs; development of communication and outreach skills in the Southampton postgraduate community, and partnership building with Nelson Mandela University, South Africa. Evidence for ocean literacy enhancement is provided by a follow-up interview study conducted with learners after the first run of the MOOC (Wintrup et al., 2015), and thematic analysis of a large number of comments posted by learners during the final week of the 4 weeks course.

Initial Quantitative Survey Data

Wintrup et al. (2015) undertook post-course interviews with 453 learners from the first run of the Exploring Our Oceans MOOC, as part of a wider study assessing the learning styles followed in MOOCs. The interview questionnaire, however, captured evidence relevant to ocean literacy goals and public engagement with research, asking participants to assess the extent to which they "learned something that changed the way I understood an issue," "felt an informed citizen," and "learned about the results of current research."

Out of the 453 learners interviewed, 100% reported learning about the results of current ocean research "sometimes" or more frequently during the MOOC, with 48% reporting that they did so "very much" (Wintrup et al., 2015). Ninety-seven percent reported that they had learned something during the MOOC that changed the way they understood an ocean issue, with 28% responding that they did so "very often" during the course (Wintrup et al., 2015). Meanwhile, 89% reported feeling that they were becoming more informed citizens sometimes or more frequently during the MOOC, with 17% doing so "very much" (Wintrup et al., 2015). Below we supplement this quantitative analysis with thematic analysis and specific quotations from learners to demonstrate the alignment with the principles of ocean literacy.

Qualitative Data From Learner Comments

More than 41,679 comments have been posted by learners and online educators across all the course runs. This significant source of qualitative data is still being processed, but an initial thematic analysis of a subset of learner comments is presented here. For this study, comments in the final week of the course from the last four runs of the course are considered, representing a total of 1,867 comments. The course format was reduced from 6 weeks (Run 1–4) to 4 weeks (Run 5–current form) so only the 4 weeks versions are included in the data set for consistency. These comments do not represent individual learners as many make multiple comments. It is beyond the scope of the current study to investigate individual commentaries/narratives. A single comment can include content relevant to multiple themes. The final week of each 4-week run was selected for analysis due to the reflective nature of the discussions and summary activities. FutureLearn's legal team have reviewed and approved this use of anonymised Learner comments with respect to terms and conditions of using the platform. This work has been conducted in accordance with the University ethics policy and values and conforms with the principles laid out in other relevant policies, guidelines and codes of conduct.

Five emerging themes around how ocean literacy can be developed through a MOOC are presented in **Table 2** below; progressing from individual engagement with concepts through to communicating and sharing new understanding more broadly across society. These themes are illustrated below with quotes from learners.

The themes are outlined below and each description is accompanied by anonymised and illustrative learner comments.

Theme 1: Developing Individual Literacy

Literacy that results from internal reflection and sharing with the rest of the cohort is common in the end of week activities, but also predominates in the final week of the course. Frequently individual literacy relates to new knowledge or understanding of key concepts in Ocean Principles, but also includes increased personal awareness of one's own actions. Where learners explicitly expressed a change in their knowledge or behavior as a direct result of the course, these comments are included in this theme. In significantly more comments, learners discussed sustainable actions but may have been engaging in these prior to their learning.

Learner B

"Some of the most striking points to takeaway... The importance of "acoustics" of Whales, Dolphins and Invertebrates Definition of the different ocean "zones"

Anthropogenic new vocabulary..."

Learner C

I now see the oceans as much larger and more diverse than I did before. I had very little knowledge of the sea floor and the vast number of organisms living there. I have gained a better understanding of how important the oceans are for the health of the whole planet, and the importance of exploiting them in a sustainable manner.

Learner D

I currently live in [location removed] and here we don't even sort our rubbish for recycling (not even paper and glass etc.). I will make an effort to try and bring about some change to this litter-friendly attitude. From now on I will also always carry around a reusable bag instead of relying on the odd plastic bag. . . .I hope to help in every way that I can.

Theme 2: Developing Literacy in Formal Education Contexts

A small but regular demographic of learners in each run are educators themselves. These participants report that they use the course materials in at least two ways: developing their own knowledge prior to teaching the subject, or alongside their students as an extension of the classroom. In a 2017 run of the course, the cohort included a class of high school students

TABLE 2 | Emerging themes of developing ocean literacy in the Exploring our Oceans MOOC (runs 5–10, 4-week version only).

Course run	Total number of comments in final week	Theme 1 (number of comments)	Theme 2 (number of comments)	Theme 3 (number of comments)	Theme 4 (number of comments)	Theme 5 (number of comments)
5	560	85	8	1	10	0
6	732	70	2	2	8	1
7	596	95	13	5	10	1
8	606	62	10	5	12	0
9	285	21	2	0	2	0
10	380	26	10	3	5	1

from Mexico whose comments and interactions indicated that they were studying with one of their teachers. Home-schooled children also access the course materials whilst supervised by parents. The cohort of learners on the MOOC is very diverse in terms of educational backgrounds, and frequently more experienced learners will help less confident or knowledgeable peers. When learner comments indicated that the individual was engaged in a classroom or home-schooled setting, or a learner had been acknowledged for providing support, the comment was included in this theme.

Learner E

Hello! I am a primary school teacher and I would like to know more about life in the ocean and influence its care and preservation through my students.

Theme 3: Developing Cross-Generation Literacies

FutureLearn has identified seven different learner "archetypes" that can be used to classify participants –Advancers, Preparers, Explorers, Flourishers, Fixers, Hobbyists, and Vitalisers. Whilst some online courses focus on professional development opportunities, others attract lifelong learners and a higher proportion of older or retired individuals who study for personal interest. Exploring our Oceans is one such course; and these learners are likely to share their new knowledge with their families.

Learner F

Living very near the sea I wanted to know more. Now I will do some of the little helpful things and try to keep at least my little patch clearer of debris and teach my children and grandchildren to be more responsible in their use of plastics and other unhelpful items.

Learner G

Living in a landlocked country [location removed] oceans are the big, mysterious waters for me, always fascinating and inviting to explore. My son (7,5) is really interested in anything that covers geography/biology, so we'll follow this course together...

Theme 4: Developing Wider Community Literacies

When learners indicated via comments that they were sharing links to course materials, or discussing the course and their new knowledge with people who were external to the course cohort, this appears in the theme of developing wider community literacies. This may be in the context of informal conversations with individuals, or with specific groups such as local voluntary clubs etc. The current thematic analysis distinguishes between the sharing of pre-existing course materials, and learners creating new resources themselves (see next section) which they then share online.

Learner H

This fourth week of a brilliant course is, I think, so important that I am copying URLs and posting on Facebook pages of several groups and friends. With acknowledgment of this course...

Theme 5: Creating New Resources for Developing Ocean Literacy in Others

Throughout the course learners are encouraged to share their knowledge and understanding with others. The "visualizing large numbers" activity in Week two is one example of such deliberate design, which enables participants to help each other comprehend the scales involved (Learners I and J). No specific direction is given in the activity instructions, but sometimes learners extend the sharing of these resources in other social platforms that they use habitually (Learner K).

Learner I

If you filled your bathtub with seawater it would contain approx. 2.8 kg of salt. (If it is an average bathtub that can hold up to 80 liters of water).

Learner J

Brilliant. Thank you [Learner I]. An excellent example on a scale I can relate to.

Learner K

Design complete and uploaded photo of drawing onto Instagram and will put one on Facebook.

In later course runs there was an increase in learners conveying a strong sense of civic duty to share their new literacies with others. Individual changes in behavior are commonly reported, with evidence that learners encourage each other to engage in beach cleans and citizen science projects. The course leaders and facilitators play an important role in providing guidance and options in how to engage with (or support) the scientific research community, local environmental communities and politicians and how to lobby government policy developers.

Learner L

I have always been an observer of the sea. With this MOOC, I feel like a "citizen of the oceans.

Learner M

My starting attempt - please hack around:

The world's oceans are the foundation of life, and as such should be protected, nurtured and only used as a resource after careful and measured scientific review. As a fellow of this course, and someone who cares about the oceans of the future - I pledge three simple things:

(*1*) *To recycle and avoid single use non-recyclables plastics.*

(*2*) *To make my use of fish an ethically based choice.*

(*3*) *To share my love and passion for the oceans, and encourage others to follow this pledge.*

Signed......

In the most recent run of the course, one learner created a pledge for peers to sign up to and share. This will be incorporated as course material into the next run and evidences a growing community of practice between learners and educators.

DISCUSSION AND RECOMMENDATIONS

Thematic analysis of the learner comments from the final week's activity provides insights into the level of ocean literacy achieved by engagement with the Exploring our Oceans MOOC. Combined with previous quantitative survey data, there is evidence for individual learning outcomes that are aligned to all seven ocean literacy principles. Higher levels of literacy, such as sharing of knowledge with others is evidenced through learner comments (themes 2–4), and the highest level (theme 5) is only occasionally evidenced in our analysis.

The combination of innovative course design based on research materials, strong educational foundations in oceanography, and the FutureLearn platform ensures free and ready accessibility for an international online audience who are able to follow course materials in English. Exploring Our Oceans has supported a diverse range of learners of all ages, with very different life experiences (Urrutia et al., 2016), and reached a global audience with wide range of motivations for taking the course, as evidenced by their feedback and continued engagement via our MOOC blog[1]. After an initial investment in the development of the first version of the MOOC, the delivery of Exploring Our Oceans is now financially sustainable with revenue streams from learner "upgrades" (extended access to course materials) which are paid jointly to FutureLearn and the University of Southampton providing funding for course facilitation by Southampton Ph.D. students.

One of the key design principles used during course development was ease of access to material online and accessibility of the material developed within the MOOC; this was designed in partnership with FutureLearn principles for delivery (Sharples, 2015). Each week involves a number of steps that develop learning in a sequential manner from knowledge acquisition through to experiential engagement in specific activities, communication of outcomes, and interactions with advanced level online research resources. Clear signposting of the learner journey means that individuals can extend their learning to greater depths if desired, or move to new areas instead. Feedback from each cohort suggests that this approach allows a wide range of learner backgrounds and expectations to be accommodated simultaneously in the same online platform. Specific lessons learnt have been incorporated into subsequent course runs and this continuous improvement allows learners to repeat the course and past learners to participate as facilitators as individuals further develop their ocean literacy.

Surveys of our students currently enrolled at the University of Southampton reveal that more than 250 have taken this free online course prior to joining the University. Feedback from this cohort provides evidence that the access to high quality and engaging learning materials was one of the key elements informing their decision to study at Southampton. Applications to marine biology and oceanography undergraduate programs at the University have increased by 30% in the 3 years from 2016 entry to 2018 entry, and although there are multiple reasons for application fluctuations, these figures are set against the background of a demographic dip in University-age individuals in the United Kingdom. Several of our Ph.D. students have taken the MOOC prior to applying to Southampton and subsequently participate in the course as postgraduate facilitators. Both undergraduate and postgraduate students (and their parents) are consistently positive about the online learning experience and recommend the course to future learners; demonstrating their acquired ocean literacy skills.

More than 35 postgraduate students, and other staff, have facilitated the online learning environment over the last 4 years. Each subsequent cohort of facilitators includes a mixture of experienced facilitators and new postgraduates. Peer-to-peer support, supplemented by training and mentoring from the MOOC leads, ensures high quality and authentic facilitation. Tutor engagement and sensitive moderation of online discussion fora are essential for learner success and this is one of the most important practical implications for those planning to use online learning to enhance ocean literacy. Tutors and facilitators answer questions, facilitate discussions, nudge learners to explore further and share learning experience. Naturally the online discussion needs occasional moderation to remove inappropriate posts, make factual corrections to inaccuracies, and to update online links. Our Ph.D. students develop their public engagement skills and facilitation confidence via asynchronous discussion of sometimes emotive subjects (e.g., sustainable use of the oceans, deep-sea mining, plastic use and pollution of the oceans) that arise throughout the course within the learning community (Urrutia et al., 2016). Our Ph.D. facilitators are all demonstrating high level ocean literacy skills through their sensitive facilitation to discussion, development of new learning materials on the course blog and other social media platforms.

One of the significant benefits for all learners and postgraduate facilitators is the exposure to online discussion fora where cohort peers with different cultural perspectives share their experiences. These can be factual observations of the ocean environment or experience from close to home in different environments, or more ocean literate views and ideas from different cultural perspectives. We have had learners who are overwintering on an Antarctic Base, learners who are based in small island states devastated by hurricanes, and learners who

[1] http://moocs.southampton.ac.uk/oceans

have never previously seen the sea. We have not yet analyzed cultural or geographical differences in the learner commentaries, and this element of analysis over the full ten cohorts could expose cultural and regional variations in ocean literacy and its development in the future.

The growth of MOOCs provided by higher education institutions in the early 2010s was partly driven by their perceived potential for increasing access to formal qualifications and continuing professional development (Yuan and Powell, 2013), particularly for learners in developing countries, but on-campus delivery remains the dominant mode of pedagogy at most universities. MOOCs have provided a medium for less formal "lifelong learning," however, and public engagement with research where MOOC content is research-led. In that context, the outcomes recorded from learner engagement in the Exploring Our Oceans MOOC demonstrate the potential of MOOCs as an important tool to help achieve ocean literacy goals as well as providing a number of other direct benefits to the organizations involved in their development and delivery. There is significant potential to accelerate ocean literacy and amplify the reach of our MOOC when learners themselves develop new resources to share with their communities. This will be our aim in future runs of Exploring our Ocean.

ETHICS STATEMENT

This study is exempt from ethics review as the research is based on studies of public behavior that are purely observational (non-invasive and non-interactive). The research has been conducted in accordance with accepted ethics standards as data have been anonymised.

AUTHOR CONTRIBUTIONS

All authors contributed to conception and design of the study, wrote sections of the manuscript and contributed to the manuscript revision, read and approved the submitted version. SF organized and analyzed the data.

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A System Dynamics Approach to Increasing Ocean Literacy

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Ocean Literacy (OL) has multiple aspects or dimensions: from knowledge about how the oceans work and our impact on them, to attitudes toward topics such as sustainable fisheries, and our behaviour as consumers, tourists, policy makers, fishermen, etc. The myriad ways in which individuals, society and the oceans interact result in complex dynamic systems, composed of multiple interlinked chains of cause and effect. To influence our understanding of these systems, and thereby increase our OL, means to increase our knowledge of our own and others' place and role in the web of interactions. Systems Thinking has a potentially important role to play in helping us to understand, explain and manage problems in the human-ocean relationship. Leaders in the OL field have recommended taking a systems approach in order to deal with the complexity of the human-ocean relationship. They contend that the inclusion of modelling and simulation will improve the effectiveness of educational initiatives. In this paper we describe a pilot study centred on a browser-based Simulation-Based Learning Environment (SBLE) designed for a general audience that uses System Dynamics simulation to introduce and reinforce systems-based OL learning. It uses a storytelling approach, by explaining the dynamics of coastal tourism through a System Dynamics model revealed in stages, supported by fact panels, pictures, simulation-based tasks, causal loop diagrams and quiz questions. Participants in the pilot study were mainly postgraduate students. A facilitator was available to participants at all times, as needed. The model is based on a freely available normalised coastal tourism model by Hartmut Bossel, converted to XMILE format. Through the identification and use of systems archetypes and general systems features such as feedback loops, we also tested for the acquisition of transferable skills and the ability to identify, apply or create sustainable solutions. Levels of OL were measured before and after interaction with the tool using pre- and post-survey questionnaires and interviews. Results showed moderate to very large positive effects on all the OL dimensions, which are also shown to be associated with predictors of behaviour change. These results provide motivation for further research.

Keywords: ocean literacy, system dynamics, simulation based learning environment, SBLE, human-ocean systems

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Abbreviations: CLD, causal loops diagram; HOS, human-ocean system; OL, ocean literacy; OLP, ocean literacy principle; SBLE, simulation-based learning environment; SD, system dynamics; ST, systems thinking.

INTRODUCTION

The functioning of the oceans and the human-ocean relationship have, up to now, been poorly understood. In the past, the ocean was for many people a remote place, used by a few as a source of food, and as a means of travel. However, the last centuries have seen a dramatic increase in its use, for oil and gas exploration, wind farms, aquaculture, tourism and much increased transport of goods. More maritime sectors are emerging, as illustrated in the EU strategy for Blue Growth. This increased pressure on the ocean makes it more pressing to protect the seas from the consequences of human use. Pressures on marine ecosystems must be reduced and the development opportunities offered by the ocean must be managed sustainably.

In recent years there have been a number of important international efforts to promote Ocean Literacy (OL).

The National Marine Educators Association (NMEA)[1] in the US has been at the forefront, worldwide, of work to define OL, centring on their '7 Ocean Literacy Principles', and to make recommendations for education in the ocean sciences. Their special report, 'Ocean Literacy Scope and Sequence for Grades K-12' (National Marine Educators Association, 2010), includes an article by Tran et al. (2010), which asserts that an absence of systems literacy impedes learning and teaching ocean sciences, with few if any examples of systems-oriented teaching initiatives found in the field of OL.

The NMEA supported the inception of the European Marine Science Educators Association (EMSEA) in 2012. Since then, the European Union has adopted the OLPs, has committed to the development of OL within the EU, and has provided for a number of OL projects under Horizon 2020, including ResponSEAble[2]. According to EMSEA, 'A more informed and concerned public will better understand the need to manage the ocean resources and marine ecosystems in a sustainable way'[3].

On 25 September 2015 the 193 countries of the United Nations General Assembly announced 17 Sustainable Development Goals, including Goal 14: 'Conserve and sustainably use the oceans, seas and marine resources for sustainable development'[4]. The 14 targets within this goal include sustainable management of fisheries, aquaculture and tourism, and an increase in scientific knowledge of the oceans.

Given the need for greater public understanding of marine issues, and for a basic level of Systems literacy needed to underpin this, we created an online OL tool that was designed to teach ocean issues and the necessary System concepts together, to a general audience. Interaction with simulations was an integral part of this. The test case was Coastal Tourism. We conducted a pilot study in December 2018 and measured the effectiveness of the tool using pre- and post-survey questionnaires and interviews.

The following sections will explore some of the concepts underlying the recommendations by the NMEA, such as complex systems, Systems literacy, what it means to take a Systems approach, the human-ocean relationship as a system, and modelling and simulation in the context of educational tools.

[1]https://www.marine-ed.org/

[2]https://www.responseable.eu/

[3]http://www.emsea.eu/info.php?pnum=17

[4]https://www.un.org/sustainabledevelopment/oceans/

BACKGROUND

Defining Ocean Literacy

The most popular definition of OL currently in use was developed by the National Oceanic and Atmospheric Administration (2013), as follows: 'Ocean literacy is an understanding of the ocean's influence on you – and your influence on the ocean.' An ocean-literate person:

- Understands the importance of the ocean to humankind
- Can communicate about the ocean in a meaningful way
- Is able to make informed and responsible decisions regarding the ocean and its resources'[5]

A survey of OL definitions reveals that in its broadest sense, it is not just what we "know", but also how we feel (our attitudes) on certain issues, how we behave in our personal and professional lives, and the extent to which we communicate about ocean-related issues with our families, friends and acquaintances. This can range from casual conversations, to promoting discussions and ideas on social media to engaging in social activism. According to the definition of Ocean Environmental Awareness proposed by Umuhire and Fang (2016), it includes a readiness to participate in marine environment actions.

For the ResponSEAble project, and this study, the authors of this paper have amalgamated the various definitions of literacy to create a framework consisting of OL dimensions (see **Figure 1**).

[5]http://www.seachangeproject.eu/seachange-about-2/ocean-literacy (accessed April 6, 2019). This page includes a useful short video explaining ocean literacy.

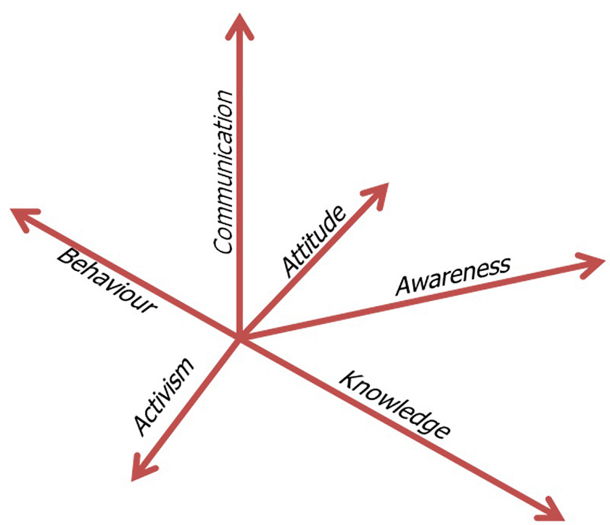

FIGURE 1 | The Ocean Literacy dimensions.

Each dimension is measured independently, and an individual can have different levels in different dimensions. We define the dimensions as follows:

- **Awareness** as the basic knowledge that a situation, problem or concept exists.
- **Knowledge** is what a person knows about an ocean related topic and the links between topics.
- **Attitude** is related to a level of agreement with or concern for a particular position.
- **Communication** is the extent to which a person communicates with others, such as family and peer groups, on ocean related topics.
- **Behaviour** relates to decisions, choices, actions, and habits with respect to ocean related issues.
- **Activism** is the degree to which a person engages in activities such as campaigning (for example through social media) to bring about changes in policy, attitudes, behaviour, etc.

Unfortunately there is no absolute scale on which we can measure these OL dimensions, so normally we are more interested in tracking shifts or changes in people's knowledge, attitude, awareness, communication, behaviour and activism.

Relationship Between the Ocean Literacy Dimensions and Behaviour Change

Numerous studies have been conducted on the links between environmental knowledge, attitude and behaviour, with sometimes conflicting results. Díaz-Siefer et al. (2015) showed that there is a correlation between greater human-environment system knowledge and pro-environmental behaviour. However, correlation does not imply causation, as numerous other studies have shown. In a study of the relationship between knowledge, attitude and behaviours toward energy consumption, Paço and Lavrador (2017) found a lack of relationship between knowledge and attitudes and between knowledge and behaviour, while there was just a weak relationship between attitudes and behaviour. Johnson and Činčera (2015) found in their work with schoolchildren that attitude change was the primary factor in promoting environmental behaviour, while knowledge alone does not often change what people do in reality. Values and attitudes are key to behaviour change. In work on pro-environmental behaviour among urban residents in Malaysia, Latif et al. (2013) found indirect links between knowledge and behaviour, with environmental values determining behaviour. In work with students, Kukkonen et al. (2018) found that scientific ecological knowledge alone is not sufficient to advance pro-environmental behaviour.

The aim of our experimental OL tool is ultimately behaviour change. In evaluating the effectiveness of the tool, changes in participants' levels of the OL dimensions are measured in order to evaluate the likelihood of behaviour change after the intervention (see section "Evaluation Methodology").

Taking a Systems Approach to Ocean Literacy

What Is a Complex System?

According to the Merriam-Webster dictionary, a system is defined as a regularly interacting or interdependent group of items forming a unified whole. A system is more than a collection of its parts (Meadows, 2008). Systems generally consist of elements, interrelationships, and an overall function or purpose (the purpose of an education system is education, and that of a digestive system is to break down food, for example). They are inherently complex, with multiple causal links between elements that can result in unexpected behaviour.

What Is Systems Literacy?

To be literate means having a good understanding of a particular subject. To be literate about Systems means to consider not only the parts but the interrelationships, patterns, and dynamics when faced with complex issues. It means embracing complexity. Linda Booth-Sweeney argues that 'most of us... were taught that the best way to understand a subject was to analyse it or break it up into parts. We were not taught the skills we need to see systems of complex cause and effect relationships and unintended impacts.'[6] She defines Systems literacy as a combination of 'conceptual knowledge (knowledge of system properties and behaviours) and reasoning skills (the ability to locate situations in wider contexts, see multiple levels of perspective within a system, trace complex interrelationships, look for endogenous or "within system" influences, be aware of changing behaviour over time, and recognise recurring patterns that exist within a wide variety of systems).'

What Is Systems Thinking?

The concept of Systems Literacy is closely related to that of ST. Arnold and Wade (2015) review various definitions of ST and its key components. The term was coined by Barry Richmond in 1987. In essence, ST is the ability to understand, represent, predict and manage dynamic complexity, i.e., behaviour that arises from the interaction of a system's parts over time. Key ST skills include discovering feedback loops, stock and flow relationships, recognising delays, identifying non-linear relationships, and understanding the boundaries of mental (and formal) models.

Barry Richmond defines ST as 'the art and science of making reliable inferences about behaviour by developing an increasingly deep understanding of underlying structure... [and] people embracing ST position themselves such that they can see both the forest and the trees (one eye on each).' (Richmond, 1994).

Like Booth-Sweeney, Arnold and Wade assert that 'Systems Thinking is widely believed to be critical in handling the complexity facing the world in the coming decades; however, it still resides in the educational margins.'

[6]https://thesystemsthinker.com/%ef%bb%bffood-systems-climate-systems-laundry-systems-the-time-for-systems-literacy-is-now/

The Benefits of Identifying Abstract Characteristics of Systems

Learning to recognise similar patterns of structure and behaviour occurring in different systems is a core ST skill. These recurring systems patterns are known as systems archetypes. They offer the opportunity for accelerated learning about newly encountered systems – with an obvious potentially positive effect on both overall environmental literacy and systems literacy. As noted by Forrester (2007), "A rather small number of relatively simple and compact structures are found repeatedly in different businesses, professions, institutions, and problems. One... junior high school student, working with bacteria in a culture and in computer simulation, observed, "This is the world population problem, isn't it?" . . . [This is the] transfer of insights from one setting to another . . .".

Examples of systems archetypes are "Tragedy of the Commons", "Limits to Growth" and "Success to the Successful" (Wolstenholme, 2003; Meadows, 2008). Systems archetypes have well-known behaviours when the system is out of control – and, crucially, they have known 'fixes'. Why try to solve each problem as if it is brand new, when tried-and-tested reusable solutions exist?

The Human-Ocean System

The HOS fits the definition of a complex system, in that it is a complex whole consisting of mutually interacting parts. Understanding the system involves a study of the whole, as well as the parts. Given the many ways that human actors interact with the ocean, an understanding of multiple perspectives, interrelationships and dependencies is needed. In order to bring about improvements in the state of the ocean, and to plan to make sustainable use of its resources in the future, it is necessary to be able to reliably predict the impact of changes to the system. These are all key ST skills (Arnold and Wade, 2015).

Mental Models

As discussed in Landriscina (2013a), certain types of human reasoning require the use of 'mental models'. Psychologist Kenneth Craik, one of the earliest practitioners of cognitive science, first laid the foundation for the concept of mental models, asserting that the mind develops these 'small-scale models of reality' on the basis of experience (Craik, 1967). They are internal representations of reality that we use to understand, reason about, and predict events. They represent knowledge, and are a relatively stable cognitive structure. According to Sterman (2002), becoming an effective Systems Thinker 'requires the use of formal models and simulations to test our mental models and develop our intuition about complex systems'.

Mental Models for Understanding Human-Ocean Systems

Where the aim is to improve understanding of a complex system in order to effect change, we need to develop and then communicate a *mental model* of the system in question.

While knowledge is just one factor in what makes people change their attitudes and behaviour, knowledge of the causal mechanisms involved allows them to make informed decisions. It also facilitates more effective communication with others.

The DPSIR framework

One causal modelling framework suitable for modelling the complex HOS is the DPSIR framework (Driver, Pressure, State, Impact, Response Framework [DPSIR], 2013), of which there are numerous variations (Patrício et al., 2016; Elliott et al., 2017). The DAPSIWR variant is useful in describing interactions between society and the environment. The letters in the acronym represent Drivers, Activities, Pressures, States, Impacts, Responses and Welfare. For the ResponSEAble project, the DAPSIWR framework was used to create causal models of six key topics or 'stories', including Coastal Tourism and Sustainable Fisheries.

Whilst this framework is useful for structuring knowledge and causal relationships flowing in one direction, it does not capture dynamics such as feedback loops, time delays, and stocks and flows, and it does not support simulation. SD models do support these features.

Modelling Complex Systems to Support Learning

There are many kinds of modelling and simulation paradigms (Landriscina, 2013a, chapter 4).

System Dynamics Modelling

System Dynamics was created during the mid-1950s by Jay Forrester (1961). It is a method for understanding the dynamic behaviour of complex systems over time. Causal loop diagrams are constructed in order to visualise a system's structure and behaviour and analyse the system qualitatively. Feedback loops and time delays are identified. The causal loop diagram, a qualitative conceptual map, is then usually transformed into a stock and flow diagram to create a more detailed quantitative analysis. A stock is the term for any entity that accumulates or depletes over time, and a flow is the rate of change in a stock. Stock and flow models demonstrate feedback, accumulation of flows into stocks and time delays. The model includes equations defining flows over time, and initial stock levels and parameters. The stock and flow model created is then typically built and simulated using computer software. This demonstrates changes in stock levels over time according to the model definition.

System Dynamics modelling has many applications and is very useful for visualising system behaviour over time, and for designing and testing effective strategies for system change.

Of the various ways to model complex systems, SD seems to us to be most suitable, since such models have been used successfully to examine complex social, managerial, economic, and ecological problems. The HOS is a form of what is variously called a coupled human-environment system, a coupled natural-human system, a socio-environmental system or a social-ecological system (SES), in which humans are seen as an integral part of the biophysical world. The 'WORLD3' model underpinning 'Limits to Growth' (Meadows et al., 1972) and the range of environmental and natural resource systems modelled by Andrew Ford (1999) are good examples of applying SD modelling to SESs. SD models are well-suited for representing such systems, since they can include the 'soft' variables often necessary when modelling human motivations, and they are useful for providing the broad, 'big picture' perspective necessary both for making sense out of inherent complexity, and for designing effective policy decisions.

Models and Simulation

According to Forrester (2007), 'It is only from the actual simulations that inconsistencies within our mental models are revealed.' And in the field of OL, 'Understanding complex systems like the ocean is difficult. However, the use of models [and] computer simulations... strongly enhance learning and teaching.' (National Oceanic and Atmospheric Administration, 2013).

Computer-based simulations rely on formalised conceptual models built by making mental models explicit, subjecting them to scrutiny and then refining them.

Simulation in Education

In their critical review of 61 studies to evaluate effectiveness of simulations used for science instruction, Smetana and Bell (2012) report on detailed findings across a wide range of factors determining the best use of simulation, including types of support, combination with other instructional methods, and their optimal order. They say that the evidence clearly demonstrates the importance of the teacher in providing guidance and support during simulation and may even replace the need for supports embedded in the software, and that 'simulations used in isolation were found to be ineffective'.

There are two main approaches to SBLE – learning by building a simulation, or by using an existing one. Learners can gain more insight from building models (Gobert and Buckley, 2000), but considerable time and skills are required. If this is not feasible, manipulation of an existing simulation offers an alternative. The approach can vary from the simplest, where learners can change a few variable values and see the consequences of their decisions on graphs, to the more complex, where learners can restructure the model. For the pilot study we have adopted the simplest approach.

The question of model opacity requires careful thought (Landriscina, 2013b). Learners interact with the SBLE through the simulation program's user interface – not with the conceptual model directly. There are 'black box' and 'glass-box' model simulations. In the former, learners can explore a system's behaviour, but the underlying conceptual model remains hidden and can only be inferred. This can lead to learners making incorrect assumptions about the conceptual model. In the latter, the simulations overtly display relationships between variables. However, this requires the learner to have some familiarity with that modelling method. One way to render the model's structure more understandable is to disclose it in stages, via a guided narrative, an approach we have taken in this pilot study.

The Challenge of Increasing Systems Literacy

Whilst the benefits of a systems approach to environmental problems are well established (Meadows et al., 1972), the challenges of teaching ST and SD are also well documented (Sweeney and Sterman, 2000; Cronin et al., 2009). People struggle to comprehend stock-and-flow and causal loop diagrams, and to visualise the dynamics of even simple systems.

ST requires a change in perspective, and a different form of reasoning than is normally applied from a non-systems perspective – a 'Paradigm Shift', to use the phrase coined by the philosopher Kuhn (1962).

OUR APPROACH

Presenting the Complex Human-Ocean System

The DAPSIWR 'stories' built for the ResponSEAble project were highly complex. The main difficulty we found was how to present this complex knowledge adequately without overwhelming the learner. We investigated a number of different approaches, including data visualisation techniques, the use of narratives, storytelling, 'story maps', guided and/or gradual display of the DAPSIWR, and web-based multimedia.

We concluded that the most promising approach was to take a Systems view. Finding and explaining the essential dynamics of the system helps to find order in complexity and can be done relatively economically. We chose one key story as a case study, Coastal Tourism, and analysed the HOS underlying it, in order to find system structures such as feedback loops, stocks and flows, and system archetypes.

Research Questions

Our work is designed to help answer the following research questions:

1. Does the inclusion of Systems Thinking and System Dynamics make teaching a specific Ocean Literacy topic more effective, in terms of faster acquisition of skills, deeper understanding, development of critical thinking skills, and/or greater retention?
2. Does the teaching of Systems Constructs and Systems Archetypes in particular help learners to transfer their knowledge from one specific Ocean Literacy topic to another?
3. Does the use of Systems Thinking and System Dynamics in Ocean Literacy education increase the ability to recognise, create or apply sustainable solutions in that domain?

Methods

Our approach was to identify those basic concepts which are essential foundations for effective system thinking. We then performed a mapping (see **Figure 2**) between these basic concepts and the phenomena which exemplify them in the key story chosen as the sample system - Coastal Tourism. We aimed to simultaneously impart ST knowledge and improved knowledge and understanding of the key story (Coastal Tourism) itself.

The System Simulation Learning Tool

This first version of the tool was designed for a general audience[7]. It is unique in using online simulation of a SD model as part

[7] http://responseable.nuigalway.ie/st/

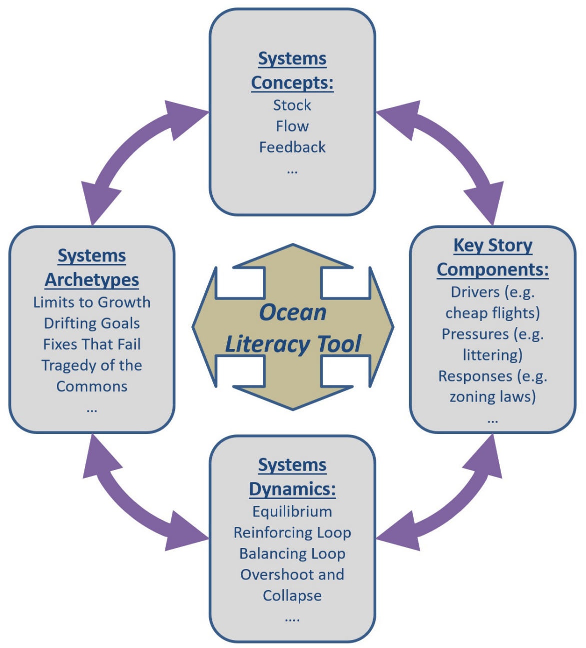

FIGURE 2 | Systems Thinking and Key Story concept map.

of an OL tool. The user is led through a series of pages which introduce and explain the Coastal Tourism story in a gradual manner. Sample screenshots are given in **Figures 3–5**.

As they progress, users can play with gradually more complex simulation models and answer quiz questions which test their understanding of the story and the relevant SD concepts underpinning it. In the simulations, users can change variables and immediately observe the effects on key stocks, such as numbers of tourists and environmental quality. A key aim of the tool is that by interacting with simulations, users will develop transferable critical thinking skills that both increase their understanding of dynamic behaviour, and provide insight into how to change system behaviour.

Essential ST tools and concepts are used to analyse the HOS that encapsulates Coastal Tourism. CLDs are central to the explanations. The model diagram is not displayed in the main pages, since it is potentially off-putting to the general user, but is available for interested users in the 'Extras' page. Fundamental Systems concepts are explained and explored, including stocks, flows and accumulation, dynamic equilibrium, feedback loops, loop dominance, the Limits to Growth (Overshoot and Collapse) archetype, structure determines behaviour, leverage points, system goals, renewable versus non-renewable resources, and sustainability.

A Systems View of the Coastal Tourism Problem

A key ST learning objective is to invite understanding of the connection between a positive feedback loop and exponential growth. Central to our systems-orientated analysis of the Coastal Tourism problem is that the unchecked growth of tourism that occurs when profits are reinvested back into tourism creates a positive feedback loop which leads directly to the exponential growth of tourists. This exponential growth is inherently unsustainable and is a powerful driver for the damage caused both to the natural environment and to the human environment if unchecked. It is powerful enough to lead to the collapse not only of environmental quality, but also to tourism at the resort under some conditions.

Key leverage points are explored, such as advertising level, growth of hotels and tourist infrastructure, and investment in the environment, in order to explore ways to bring the system into a sustainable state. Participants can use simulations to actively explore the effects of changing these key variables, and can practise bringing the system toward sustainability, a system state that is described as one where tourism can continue over time, rather than peaking and then collapsing, within a healthy coastal and human environment.

In order to investigate Research Question 2, we drew comparisons between the Coastal Tourism model and Sustainable Fisheries, since both can exhibit the 'Overshoot and Collapse' archetype. An in-tool quiz question then invited participants to identify a similar pattern of behaviour in other diverse systems.

Ocean Literacy Content

The prototype online interactive SBLE centres on one key story – Coastal Tourism – and highlights the similarity of the dynamics inherent in another key story, Sustainable Fisheries. The source material is based on the Key Story DAPSIWR analyses documented for the ResponSEAble EU project.

Learning Objectives

A set of learning objectives was established for the key story (Coastal Tourism), comprising the relevant OL knowledge, systems knowledge, and the knowledge required for identification of sustainable solutions (see **Tables 1**, **2**).

Models Used

The SD model on which the simulations were based was the generic, normalised Simulation Model Z412B, described and documented in Hartmut Bossel's System Zoo 2 (Bossel, 2007). The original Bossel model is in Vensim format, and is available for free download[8]. It is not a calibrated model based on empirical data for a specific coastal tourism resort over a particular period in time; rather, it is an illustrative, qualitative model, suitable for teaching the main structures and dynamics of a typical coastal tourism system.

We recreated the model in Stella Architect in order to obtain a version in XMILE[9] format, required by the software library sd.js (see section "Software Platform"). XMILE is the emerging standard for storing and sharing SD models.

We supported a story-telling approach by creating two simpler models that built in complexity toward the final model. The first model introduced the stock Environmental Quality, and its flows, Degeneration Rate and Regeneration Rate. The second

[8]Contained within ZOO MDL.zip, available for download from the Centre for Environmental Research, University of Kassel, Germany, at https://www2.cesr.de/
[9]https://www.oasis-open.org/committees/xmile/

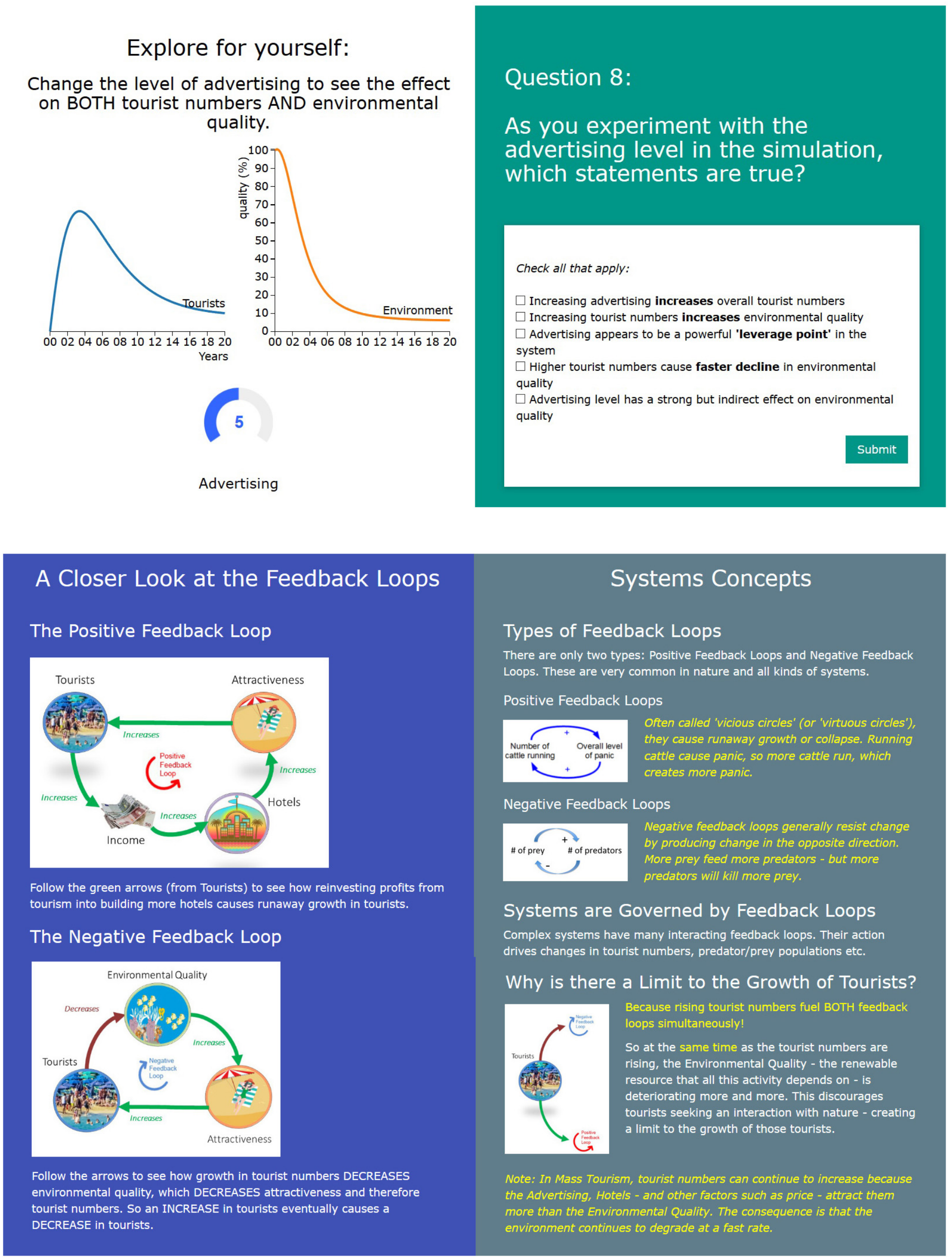

FIGURE 3 | OL tool screenshots: simulation showing two key stocks and a key variable, together with a reinforcing in-tool quiz question; feedback loops explained using Causal Loop diagrams, both in the context of Coastal Tourism, and in general System Thinking terms (RQ1).

model added the stock Tourists and the variables Advertising and Attractiveness. The final model includes a third stock, Hotels, and variables Hotel Investment Rate and Investment in the Environment.

Software Platform

We used the Open Source simulation tool, sd.js[10]. This is a Javascript-based library for fast, in-browser SD model simulation that reads models in XMILE format and uses D3 to construct interactive graphs and jQuery to implement interactive variable controls.

[10]https://github.com/bpowers/sd.js

Teaching Environment

We designed this platform for use in combination with face-to-face teaching individually or in groups, following best practise for Simulation Based Learning Environments (SBLEs) (Landriscina, 2013a) and Systems teaching (Fisher, 2011).

FIGURE 4 | OL tool screenshots: description of the Limits to Growth Archetype and its relevance to Coastal Tourism, together with a reinforcing in-tool quiz question; application of the same Archetype to Fisheries, and quiz question to test for recognition in other systems (RQ2).

Data Captured

Pre- and post-test surveys

Before using the OL tool, the participants completed a survey which assessed their current level of OL on the topic of Coastal Tourism, in terms of the OL dimensions. After use of the tool, participants completed a post-test survey consisting largely of the same questions as the pre-test, in order to assess effectiveness of the tool in increasing OL levels.

Most questions were scale based (0–10) and designed to assess whether a change in awareness, knowledge, attitude, social and personal norms (communication) and reported or intended behaviour had taken place. Other questions were designed to elicit qualitative responses relating to current coastal holidaymaking behaviour, awareness of problems with coastal tourism and understanding of the concept of sustainability. The post-survey contained additional questions to gather opinions about the usefulness of the simulations and the tool itself.

Qualitative feedback interviews

The facilitator observed and noted user interaction with the tool and gathered verbal feedback both during the training and afterward in a moderated feedback session (structured around key questions).

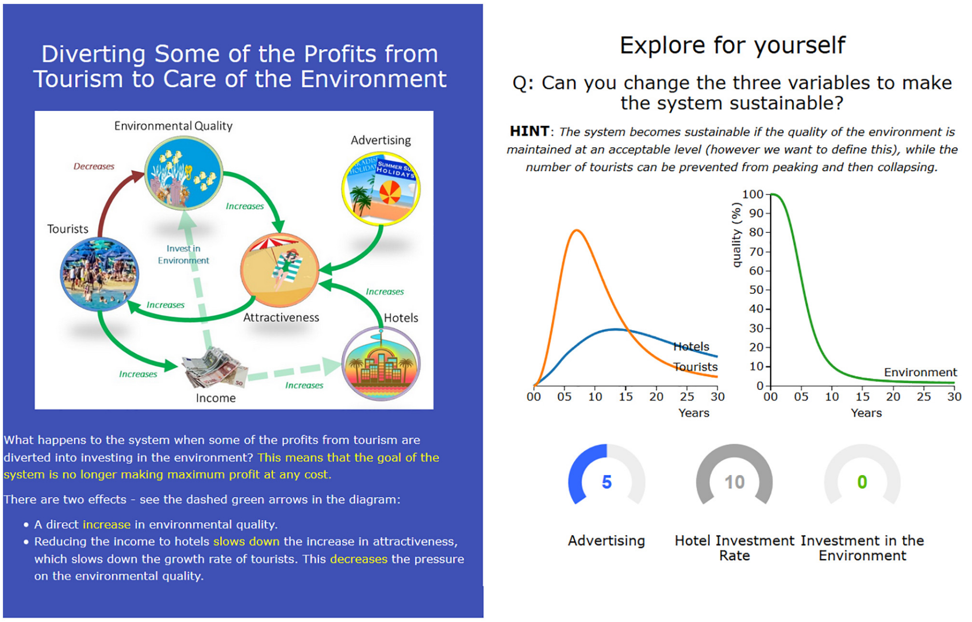

FIGURE 5 | OL tool screenshot: illustration of changing the system structure for sustainability, and a simulation giving users an opportunity to practise bringing the system into a sustainable state by manipulating model variables (RQ3).

TABLE 1 | Ocean literacy and systems thinking learning objectives identified (part 1).

Page	Title	Learning objectives	OL/Key story learning points	Systems thinking principles; *application*
Intro	Introduction	Traditional '3S model' for coastal tourism in Europe: sea, sand and sun. Massive increase in tourist numbers is devastating the coastal environment and causing decline in traditional local employment and quality of life.	The Human-Ocean System is a complex system [*OLP 6*].	Systems thinking provides major insights for tackling complex, practical problems like these.
1	The natural state of the coastal environment	The coastal environment renews itself naturally. It can deal with naturally occurring degeneration, to maintain a consistently healthy state - a constantly changing, but stable, state known as "dynamic equilibrium." Apply systems concepts to see environmental quality (EQ) as a stock, and degeneration and regeneration rates as flows. Understand that EQ is affected only by these flows. Think about how human activities affect these flows.	Equilibrium disturbed Degeneration rate caused by tourism exceeds natural regeneration rate	• Stocks • Flows • A stock changes only according to its flows • Accumulation of stock according to net flows • Dynamic equilibrium • *Environmental quality identified as a stock* • *Regeneration and degeneration rates identified as flows*
2	Mass tourism and its effect on the coastal environment	Massive and ongoing increase in tourist numbers internationally. Europe the most popular destination. Latest global tourism figures. Direct relationship between increasing tourist numbers and decreasing environmental quality. Examples of damaging effects of coastal tourism. Typical characteristics of mass coastal tourism.	Environmental stresses caused by Tourism, and Mass Tourism in particular [illustration of *OL6D*].	• *Tourists increase degeneration rate (outflow of environmental quality)* • *Tourists therefore decrease environmental quality*
3	Countering the effects of mass tourism on the coastal environment	Typical responses to reduce the damage done by costal tourism. Classification of responses according to whether they affect degeneration or regeneration rates. Are such responses enough, or is wider system change needed?	The Human-Ocean System is a system [*OLP 6*]. Much of the world's population lives in coastal areas [*OLP 6F*].	• What is a system? • What is systems thinking? • System structure determines behaviour • Leverage points

TABLE 2 | Ocean literacy and systems thinking learning objectives identified (part 2).

Page	Title	Learning objectives	OL/Key story learning points	Systems thinking principles; *application*
4	Case Study: a coastal resort where nature is the main attraction	Analysis of a particular type of resort: one which attracts nature-loving tourists, such as snorkelling resort. If the fish disappear, so too will the snorkellers. Advertising brings in tourists, who then degrade the environment. Tourist numbers initially rise quickly, but then fall, because the attraction was nature-based.	The effects of human activity on the ocean [*OLP 6D*]. Our responsibility [*OLP 6G*].	• Causal loops diagrams • Feedback loops • *Identify chain of causality (indirect causation)* • *Advertising level identified as a Leverage Point*
5	Uncontrolled growth	Hotels and profits from tourism are added to the model. Tourists are now attracted by 3 factors: advertising, hotels and environmental quality. All profits from tourism are re-invested in tourism in this model. This leads to uncontrolled and unsustainable growth. Explanation of why this type of growth often follows a 'boom and bust' pattern, and leads to serious environmental damage.	The ocean sustains life on Earth and humans must live in ways that sustain the ocean [*OLP 6G*].	• Positive and negative feedback loops: the only two types • Identification of feedback loops • Systems are governed by feedback loops • Loop dominance • Limits to growth: *feedback loops cause rapid growth and subsequent collapse in tourists, because environmental quality, a renewable resource, is depleted*
6	Systems thinking for sustainable tourism	Understanding that the overshoot and collapse pattern is a common system pattern of systems behaviour. Its characteristic "crash" can be avoided. Why systems skills are useful for identifying and fixing common Systems problems. Identifying renewable resources.		• Dynamics of the "Overshoot and Collapse" generic Systems structure • Comparison with another HOS: fisheries • Learning to identify other systems exhibiting similar behaviour • Learning from systems thinking: applying known strategies to fix systems of similar structure
7	Toward sustainability	Definition of Sustainable Development and Sustainable Tourism. Three aspects: environmental, economic and social. Simulation-based practise at bringing the System into a sustainable state, where the quality of the environment is maintained at an acceptable level (however defined), and the number of tourists can be prevented from peaking and then collapsing.		• *Herman Daly's Rules for a Sustainable Society* • Changing system goal as key leverage point • Changing system structure as key leverage point: e.g., introducing new feedback loops, weakening or strengthening existing loops

Answers to in-tool questions

There were 13 multiple-choice questions embedded in the tool. Answers to these were captured and stored on the NUIG ResponSEAble server, and downloadable in CSV and JSON format for analysis.

Evaluation Methodology

Measuring Effect Size

Each survey question was designed to measure one of the OL dimensions (knowledge, attitude, behaviour and so on). Where answers for a particular question were given on a scale from 0 to 10, the mean of answers from all the participants was calculated, before and after interaction with the tool. The results were grouped by OL dimension. The difference in each OL dimension was then analysed using 'Cohen's d' (Cohen, 1988), a statistical measure of the effect size, calculated by taking the difference between the two means and dividing by the pooled standard deviation (i.e., the root mean square of the two standard deviations).

Measuring Effectiveness of the Ocean Literacy Tool

A framework was applied and tested in the ResponSEAble project to identify strengths and weaknesses of OL initiatives. Effectiveness was assessed in terms of the potential for behaviour change. Unfortunately, this is difficult to measure directly; however, it is possible to measure *predictors* of behaviour. We employed assessment frameworks and methodologies which draw on psychology and behavioural research concepts and methods to analyse predictors of behaviour change.

Assessing Potential for Behaviour Change

To assess effectiveness of the OL tool, the OL dimensions were integrated with predictors of behaviour change identified in social science and psychology literature (Klöckner, 2013; Phal and Wyles, 2017).

In a study of the psychology of environmental behaviour, Klöckner (2013) concluded that the best direct predictors of behaviour were:

- Intentions ("I will do this").
- Perceived behaviour control ("It is up to me whether I do this rather than other people or contextual factors").
- Habits (behaviours that have become automatised through repetition).

Factors having an indirect effect on behaviour were identified as:

- Attitudes (favourable or unfavourable evaluations).
- Norms (what is seen as commonly done by others).

- Responsibility (ascriptions of who should deal with the problem).
- Awareness of consequences (knowledge about impacts).
- Values (general trans-situational goals such as equality or individualism).

Other studies have identified further factors:

- Negative emotions such as worry, and positive emotions such as hope (Ojala, 2008).
- People who regard themselves as environmentalists may exhibit more environmentally conscious behaviour (Whitmarsh and O'Neill, 2010).

These ten social and psychological concepts can be measured empirically and provide important means of changing behaviour beyond information and knowledge provision (Phal and Wyles, 2017).

The relationships between the ten predictors of behaviour change, the OL dimensions, and the corresponding questions used in the pre- and post-surveys for assessing the effectiveness of the OL tool are shown in **Table 3**.

A theory of change logic model

In defining the process to achieve behaviour change objectives, we adopted the Theory of Change logic model (Connell and Kubisch, 1998) and the 'PRECEDE-PROCEED' model developed by Green and Kreuter (1999).

The PRECEDE-PROCEED model is a step-by-step planning and evaluation model, originally aimed at directing behaviour change processes in health promotion. Central to the model is the principle that a change process should focus on the outcome, not the activity. Originally applied to initiatives that promoted behaviours to reduce the incidence of major causes of death and disability, it has been widely adopted in environmental awareness programmes, including the OL dimension related predictors of behaviour change.

A Theory of Change logic model was completed in collaboration with social and behavioural science researchers at the University of Plymouth and ProSea[11] tool developers. The formulation of the Theory of Change steps designed to achieve behaviour change were guided by predictors of behaviour identified in the OL dimensions (**Table 4**).

Predictors of behaviour change and OL dimensions can be assessed using research techniques such as surveys, repeated pre and post interaction with the OL tool (Phal and Wyles, 2017). In order to assess change over time, the same questions can be asked before and after interaction with the tools, and again during longer follow-up studies as necessary.

Questionnaire surveys were conducted with course participants before and after interacting with the OL tool. Each survey question addressed an objective within the Theory of Change framework and therefore an OL dimension.

[11] http://www.prosea.info/

RESULTS

The ST for OL tool was piloted for the ResponSEAble project in December 2018 in Galway, Ireland, in a series of one-to-one sessions with 15 adult participants (9 women and 6 men), eleven of whom were Ph.D. students, one retired local council manager, a Masters student, an engineering graduate, and a teacher. Participants were aged between 18 and 64 years, with the majority (two thirds) in the age range 35–54. A facilitator was available at all times for guidance as required by each participant. The participants took an average of 40 minutes to work through the tool, and another 30 minutes in total filling in pre- and post-test surveys and giving qualitative feedback.

Survey Questionnaire Results

Quantitative Survey Answers

Answers to pre- and post-survey questions with quantitative answers (on a scale 0–10) were analysed for effect size with regard to change in the OL dimensions using Cohen's d (see **Table 5**). 0.20 is considered a small effect, 0.50 is medium, 0.80 is large, and >1.20 is very large. The table shows that the effect on knowledge, communication and (intended) behaviour was very large, and that on barrier removal and attitude was moderate. All effects were positive, i.e., indicating an increase.

The same data are summarised, broken down by four OL dimensions, using a radar chart (**Figure 6**). Taking each dimension in turn, the chart illustrates that:

- **Attitude** levels were quite high before the intervention, meaning that participants were already worried about the damage caused by coastal tourism.
- They did not often **communicate** about these issues, however.
- They had only moderate confidence in their **knowledge** about how coastal tourism affects the marine and the human environment.
- They were only moderately likely to take action to reduce the negative effects of coastal tourism (**behaviour**).

All these OL dimensions increased in the post-test survey. For the mean scores, pre- and post-survey, and the percentage change, please see **Tables 6**, **7**. **Table 6** gives an overview by OL dimension, whereas **Table 7** presents results per question. These tables demonstrate that the largest percentage increases were for how often participants intended to communicate about the effects of coastal tourism on the marine and human environment, their intention to take action to reduce the negative effects of coastal tourism (behaviour), and their self-reported level of knowledge about the issues.

It is worth noting that the relatively low (18%) increase in how concerned participants felt about the effects of coastal tourism on the marine environment (attitude) does not mean that the tool was less successful in this regard, since the pre-test level of concern was higher than for all the other OL dimensions.

Qualitative Survey Answers

Regarding their criteria for choosing coastal holidays (**Figure 7**, first question), many participants did not think much about

TABLE 3 | Relationship between questions developed to assess effectiveness of the Ocean Literacy tool, predictors of behaviour and Ocean Literacy dimensions assessed.

Predictors of behaviour (Klöckner, 2013)		**Ocean Literacy dimensions applied in assessment *(text in brackets indicates an indirect connection)***	**Questions used in pre- and post-intervention survey [0 (*not at all*) – 10 (*a lot*/*very*) scale based responses, unless otherwise shown]**
Best direct predictors of behaviour	**Intentions** ("I will do this.")	• **Behaviour: decisions, choices, actions, and habits** • **Activism**	*Note: These 4 questions initially assess current behaviour ('I. . .') (in pre-test), then intended behaviour ('I will. . .') (in post-test):* "When on holiday on the coast I (will) separate litter for recycling." "When on holiday on the coast, I (will) look to use businesses that reduce their negative impact on the environment." "When planning a holiday on the coast I (will) look for towns or resorts where council officials have introduced schemes to reduce negative impacts from tourism." "I (will) look for information on sustainable tourism practises that I can undertake in the areas I visit."
	Perceived behaviour control ("It is up to me whether I do this rather than other people or contextual factors.")		"I believe there will be a benefit to the marine environment and human health and happiness if I support sustainable tourism activities (e.g., recycling and using businesses that limit their environmental impact)."
	Habits (behaviours that have become automatised through repetition.)		On average, how many times a year do you visit the coast in the country where you live in your spare time? *(No of times)* In the last three years, how many times have you been on holiday abroad to a coastal resort? *(No of times)* If so, which regions did you visit? *(circle regions)*
Factors having an indirect effect on behaviour	**Attitudes** (favourable or unfavourable evaluations.)	• **Attitude**	What do you think are the biggest causes of problems facing coastal resorts? *(rank 5 items listed)*
	Norms (what is seen as commonly done by others.)	• **Communication**	How often do you (will you) talk about ways of helping to reduce the problems coastal tourism may cause in the ocean with your family, friends, colleagues or teachers?
	Responsibility (ascriptions of who should deal with the problem.)	• (Attitude)	Not assessed.
	Awareness of consequences (knowledge about impacts.)	• **Knowledge**	"I have good knowledge about how coastal tourism activities affect the marine environment." "I have good knowledge about how coastal tourism activities may affect human health and happiness."
		• **Awareness**	When you think about Coastal Tourism, what are the most important environmental issues that come to mind? *(Please list between 1 and 3 issues)*
	Values (general trans-situational goals such as equality or individualism.)	• (Attitude)	What were your criteria for choosing a particular coastal resort? *(please put your most important reasons first)*
	Negative and positive emotions (such as worry or hope.)	• (Attitude)	"I am very worried about damage caused by Coastal Tourism to the natural environment" How worried are you about the effects of the most important environmental issues that came to mind?
	Whether people see themselves as environmentalists.	• (Attitude) • **Activism**	"I support projects to restore coastal and marine habitats that have been degraded by coastal development"

it, and did not record their criteria in the survey, but if they did, they made their choice on the basis of facilities (including sun/sea/sand) and cost. After using the tool, there were more varied responses given, and a marked change in priorities for planning intended future coastal holidays: environmental quality or impact, and sustainable or responsible tourism, were most often given as criteria.

From pre- and post-survey answers to a question asking participants to write down their understanding of the concept of sustainable coastal tourism, there was some evidence of a richer understanding post-survey (in terms of dynamics and balance).

Responses showed an increase in the number of issues participants were aware of post-survey, a greater emphasis on the need for sustainability and investment in the environment (**Figure 7**, second question). Responses to a survey question about perceived causes of coastal tourism related problems demonstrated an increased awareness of the need to impose regulations on coastal tourism development.

TABLE 4 | Theory of change logic model developed to assess effectiveness of OL tool.

	Problem awareness	Knowledge	Attitude	Communication /social norm	Barrier removal	Behaviour change
Theory of change: **Aim**	Following the intervention, participants will be aware of the issue or problem.	Following the intervention, knowledge about the issue will have increased.	Following the intervention, attitude will change, behaviour change supported, and confidence in response increased.	Following the intervention, participants will communicate about the issue or topic with others.	Barriers that prevented the behaviour change will be reduced/removed.	Behaviour adopted or intention expressed:
Coastal Tourism example	(i) Tourists to recognise threat to marine environment. (ii) Tourists to recognise threat to human health and happiness.	Tourists to recognise: (i) Massive increase in Coastal Tourism since the 1950s. (ii) Types of damage done to the environment. (iii) Types of damage done to the human environment. (iv) Some responses to reduce the damage. (v) Understanding dynamics of the system e.g., positive feedback loops. (vi) Reducing growth and investing in the environment for a more sustainable solution.	Tourists believe/recognise that: (i) Mass tourism causes damage to the coastal and local human environment. (ii) Making sustainable tourism choices reduces the damage. (iii) Supporting projects to restore coastal environment helps.	(1) Tourists will communicate with others about: (i) Threats created by mass coastal tourism. (ii) Options to reduce the damage. (2) They will seek information on sustainable tourism.	Knowledge of options or actions that reduce the damaging effects of coastal tourism. Belief that participants can make a difference.	(1) Tourists to choose sustainable forms of coastal tourism. (2) Tourists to behave in environmentally conscious ways when on holiday. (3) Informed tourists to support initiatives to repair coastal environments.
Measurable objective (indicator)	Pre- and post-survey.	Pre- and post-survey.	Pre- and post-survey.	Pre- and post-survey.	Pre- and post-survey.	Pre- and post-survey (reported/intended behaviour).
Result (from pilot study) (mean # pre – > mean # post, on a scale of 0 (not at all) to 10 (a lot / very)	Awareness assessed qualitatively: more issues listed by participants, greater emphasis on sustainability and importance of regulations.	67% increase in mean self-reported knowledge of damage done to the natural and human environment (4.6 - > 7.7). This relates to points ii and iii above. Other points not directly addressed but the topics were covered in the tool, and informed other survey responses.	18% increase in mean level of participants' reported worry about the issues (7.2 – > 8.5).	142% increase in mean level of frequency of participants' actual and intended communication (2.6 – > 6.3).	14% increase in mean level of participants' response that they believed there would be a benefit if they support sustainable tourism activities (7.8 – > 8.9).	88% increase in mean level of participants' intention to act to reduce damage done by coastal tourism (4.3 – > 8.1).

TABLE 5 | Measuring effect size of pre- and post-survey scaled question results using Cohen's d.

	Mean before	Std. Dev. before	Mean after	Std. Dev. after	Cohen's d	Result
Attitude	7.16	2.26	8.50	1.61	0.71	Moderate positive effect
Attitude (Barrier removal)	7.78	2.71	8.87	1.56	0.51	Moderate positive effect
Knowledge	4.64	1.93	7.68	1.52	1.81	Very large positive effect
Communication	2.63	2.77	6.33	2.55	1.45	Very large positive effect
Behaviour	4.31	3.44	8.08	1.61	1.45	Very large positive effect

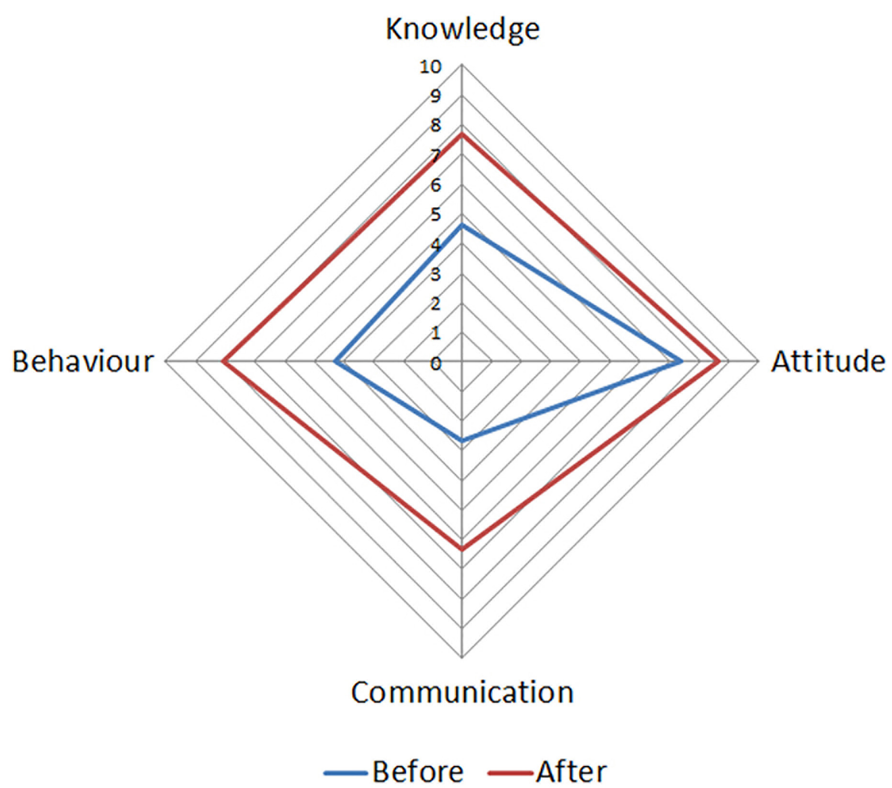

FIGURE 6 | Radar chart showing changes in four of the dimensions of Ocean Literacy before and after use of the tool.

Finally, all participants said that they found the simulations useful for improving their understanding of the dynamics of the Coastal Tourism system. When asked what they found most memorable about the tool, most participants cited interacting with the simulations and discovering the dynamics of the system.

Data From In-Tool Quizzes

The in-tool quiz questions served mainly to provide learning challenges for the participants, to help them engage and practise applying new OL and Systems concepts. The recorded answers helped us, as tool developers, to obtain feedback and thereby improve the efficacy of the presentation approach.

One third of participants gave incorrect answers for reading the Causal Loop Diagrams. Taken together with participants' comments on this topic, outlined in the next section, this suggests an area for improvement in the tool.

Participants scored well (13/15 correct) on the question testing their understanding of how to bring the coastal tourism system to a sustainable state (RQ3). They also scored better than expected (11/15 correct) when identifying systems with similar structure (archetype) (RQ2). They scored less well (8/15 correct) when asked to identify factors that fuel a 'boom and bust' ('overshoot and collapse') dynamic. This part of the tool therefore needs further work.

Qualitative Feedback Given by Participants and Observations Made While They Interacted With the Tool

(1) Regarding the quantity of material: A number of people found that following the tool required too much reading and concentration. Sections should not be too long.

Respondents took an average of about 45 minutes to work through the material and answer questions. Many of them commented that this was too long. 20–30 minutes would be acceptable.

TABLE 6 | Pre- and post-survey scaled question results, summarised by OL dimension and percentage change.

OL dimension	Mean before	Mean after	Change	Stacked bar (scale 0–10)
Attitude	7.2	8.5	1.3 (+18%)	
Attitude (barrier to behaviour change)	7.8	8.9	1.1 (+14%)	
Knowledge	4.6	7.7	3.1 (+67%)	
Communication	2.6	6.3	3.7 (+142%)	
Behaviour	4.3	8.1	3.8 (+88%)	

(2) Use of systems terminology such as stocks and flows, feedback loops: Some participants thought this was off-putting. One participant said that the Systems concepts were the most challenging. One participant reflected out loud, "*.. are we educating people about Systems Thinking and/or System Dynamics (to improve Systems Literacy in general), or are we trying to educate them in a specific domain (in which case the less jargon the better?)*." Another said that the system is designed too much around academic concepts and would lose members of the general public. Another thought that it did take a lot of concentration but that having to think about the "*learning points*" meant that she learned something of value.

(3) Different needs of different types of user, from general public to technical: For general users with no knowledge of ST/SD it might be hard for them to stay focused all the way to the last page. What exactly is the intended audience? This needs to be better defined.

TABLE 7 | Pre- and post-survey individual scaled question results, summarised for all 15 participants by percentage change.

Question	OL dimension	Scale	Mean before	Mean after	Change	Stacked bar (scale 0–10)
I am very worried about damage caused by Coastal Tourism to the natural environment	Attitude	0 (completely disagree) to 10 (completely agree)	7.2	8.5	1.3 (+18%)	
How worried are you about the effects of the most important environmental issues that came to mind?	Attitude	0 (not all concerned) to 10 (very concerned)	7.2	8.5	1.3 (+18%)	
I believe there will be a benefit to the marine environment and human health and happiness if I support sustainable tourism activities	Attitude (barrier to behaviour change)	0 (completely disagree) to 10 (completely agree)	7.8	8.9	1.1 (+14%)	
How often do you/will you talk about ways of helping to reduce the problems coastal tourism may cause in the ocean with your family, friends, colleagues or teachers?	Communication	0 (not all all) to 5 (some of the time) to 10 (all of the time)	2.6	6.3	3.7 (+142%)	
I have good knowledge about how coastal tourism activities affect the marine environment	Knowledge	0 (completely disagree) to 10 (completely agree)	4.5	7.8	3.3 (+73%)	
I have good knowledge about how coastal tourism activities may affect human health and happiness	Knowledge	0 (completely disagree) to 10 (completely agree)	4.7	7.5	2.8 (+60%)	
When on holiday on the coast I (will) separate litter for recycling	Behaviour	0 (not all all) to 5 (some of the time) to 10 (all of the time)	7.2	9.1	1.9 (+26%)	
When on holiday on the coast, I (will) look to use businesses that reduce their negative impact on the environment	Behaviour	0 (not all all) to 5 (some of the time) to 10 (all of the time)	4.6	8.4	3.8 (+83%)	
When planning a holiday on the coast I (will) look for towns or resorts where council officials have introduced schemes to reduce negative impacts from tourism	Behaviour	0 (not all all) to 5 (some of the time) to 10 (all of the time)	2.9	7.6	4.7 (+162%)	
I (will) look for information on sustainable tourism practises that I can undertake in the areas I visit	Behaviour	0 (not all all) to 5 (some of the time) to 10 (all of the time)	3.1	7.6	4.5 (+145%)	
I (will) support projects to restore coastal and marine habitats that have been degraded by coastal development	Behaviour	0 (not all all) to 5 (some of the time) to 10 (all of the time)	3.8	7.7	3.9 (+103%)	

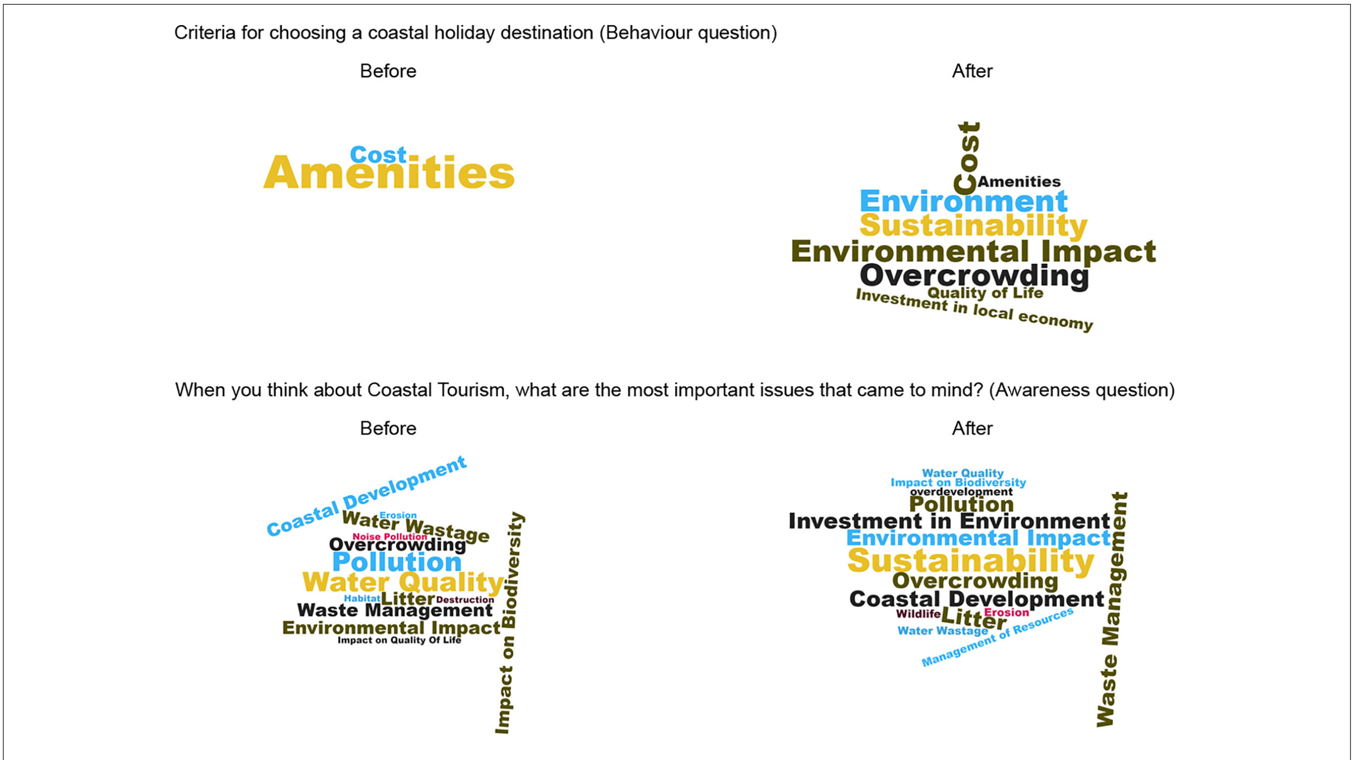

FIGURE 7 | Wordclouds representing before and after survey responses for two qualitative questions.

(4) Visual versus textual content: A number of participants wanted more visual material (video, animation or slideshow with voiceover), instead of long sections of text and static diagrams. More interaction would help keep users engaged. A narrator with a strong storyline would help.
(5) Response to in-tool quiz questions: Participants' reaction to these varied. A majority became visibly worried about 'getting answers wrong'. Others found the reinforcing of learning from material on the page useful. A few said they enjoyed the challenge. Some questions and answers caused confusion and needed clearer wording.
(6) Understanding of dynamics of the system: Most people expressed a new understanding of the importance of the major drivers in the HOS under investigation, for example, the effect of huge increases in tourist numbers, and the powerful effect of feedback loops.
(7) Difficulty with Causal Loop Diagrams: Reading CLDs caused a bit of confusion, mainly with regard to how to read the arrows. We annotated arrows with 'increase' and 'decrease' – e.g., A increases B, which means 'As A increases, B increases.' But if A *decreases* instead, then users need to understand that B will *decrease*. One participant suggested letting users practise creating their own causal loops.
(8) Issues with the models underlying the simulations: Some participants pointed out flaws with the simulation models, for example, unexpected behaviour of stocks (tourists, hotels or environmental quality) when variables were set at extremes, i.e., at minimum or maximum values. Models need to be thoroughly tested at the extremes in order to avoid causing potential confusion for learners. Our models, based on Bossel's, are normalised, i.e., unitless. They are useful for showing general dynamic trends but some users commented on the lack of y-axis scales on some graphs, and the lack of concrete figures.
(9) Facilitation versus unsupervised self-study: Most people thought that a facilitator would be preferable for this type of material. Alternatively, facilitator sessions could be recorded and video clips included in the tool for each major topic.
(10) Learning by using the simulations: Most people said that they found the interactive simulations useful and enjoyable to use. Learning by experimenting is effective and can give unexpected results. The last simulation in the series attracted a lot of positive comment. In it, users attempt to manipulate three variables in order to bring the system to a sustainable state. The most interesting suggestion was that it should be possible, after attempting the task, to display a pre-prepared answer (variables would be set for a sustainable outcome, visible on the graphs).
(11) Perceived limits of the influence of the public: One participant pointed out that policy changes are needed, as well as actions by individuals, in order to reduce the damage caused by coastal tourism. The systems view arguably emphasises the policy ('big picture') point of view.

Sample of Spontaneous Feedback During Post-tool Interviews

'Genuinely eye-opening, much more concerned about the problem than before.' [Increased awareness/attitude of concern].

An interesting response to pre-questionnaire behaviour questions: '*If I'm on my holidays, I'm on my holidays!*' – meaning, I don't want to have to think about recycling and being environmentally responsible. [Reveals attitude].

'*It's both too easy and too hard at the same time. It requires a level of concentration people probably won't want to give.*' People would need to be motivated by interest in the subject. '*Could be used as a teaching tool by a facilitator.*' [Comments by a teacher].

Some Comments Left In-Tool

'Understanding how to work towards Sustainable Tourism has opened my eyes to what I can do to help.'

'Good resource - this is engaging, it made me think, taught me a little about Systems Thinking, raised my consciousness about choosing holidays and amenities that have a sustainable approach, and a concern for the environment.'

DISCUSSION

We have not been able to find existing applications of SD (or other) simulation in the context of OL. In the related field of climate change education, Moxnes and Saysel (2009) describe in detail an experiment involving simulation which was designed to correct common misperceptions of carbon dioxide accumulation and its consequences. They report 'promising learning effects'. In his paper on communicating climate change risks, Sterman (2011) argues that, where misunderstanding of a complex system is the norm, and where there is an urgent need to correct the mental models of the public and policymakers, these problems 'cannot be remedied merely by providing more information about the climate, but require different modes of communication, including experiential learning environments such as interactive simulations.' The C-ROADS Climate Change Policy Simulator[12] is based on a SD model and is used by policy makers and the public to better understand how to reduce greenhouse gas emissions and to test strategies for dealing with climate change (Sterman et al., 2012).

The results of this pilot study are in line with other studies where computer simulations have been found to enhance outcomes in science education (Rutten et al., 2012). Our work addresses the need to introduce a Systems approach and simulation to the field of OL (Tran et al., 2010) and adds to work done with SD modelling and simulation in the related field of environmental literacy. Whilst the SD model underlying the C-ROADS Climate Change Policy Simulator described by Sterman has been tested, we cannot find studies that test C-ROADS for effectiveness in terms of learning outcomes or support for policy making, which suggests a gap in the research that this study has the potential to address.

[12]https://www.climateinteractive.org/tools/c-roads/

Increase in Ocean Literacy and Systems Literacy Levels

The results of the pilot study show a significant increase in the OL dimensions for participants (knowledge, attitude, behaviour, and so on). Participants showed a better understanding of the complex dynamics of the HOS underlying coastal tourism, and developed a more dynamic understanding of the concepts of sustainability and sustainable tourism (Research Question 3). This understanding was in addition to, and arguably provided a mental model as context for, the more usual issues and mitigating responses described in non-Systems oriented OL initiatives.

All participants said that they found the simulations useful. This suggests that it will be worthwhile to investigate further the possibility that ST and SD can be used to create effective educational tools for increasing OL (Research Question 1).

Participants also scored well when recognising a generic Systems structure (a Systems archetype) as applying to other systems (Research Question 2). There is evidence, therefore, that their Systems Literacy, as well as their OL, has improved through use of the tool.

Recommendations for Enhancing the Ocean Literacy Tool

The next version would need to be refined according to the feedback received from participants and observations made when watching them interact more or less successfully with different aspects of the design.

- The prior knowledge and technical aptitude of the target audience would need to be more closely defined.
- Appropriate, possibly simplified, terminology and diagrams should be used for the theoretical Systems aspects. Whilst some participants struggled with terms such as stocks, flows and feedback loops, attempting to teach ST without them may be too limiting. The use of an alternative, simpler set of terms, and assessment of their usefulness, would be an interesting topic for research.
- Creative ways, possibly animated, of presenting Causal Loop Diagrams should be explored. There are a number of existing alternatives for annotating arrows between variables, but none easily solve the problem of clearly representing the differing causal result in the second variable that arises depending on whether the first variable increases or decreases. Some form of novel presentation such as animation could be considered, or use of a short teaching video clip. Users could perhaps hover over an arrow to get both senses of its meaning.
- The length of the session should probably not exceed about 30 minutes, and a facilitator would ideally be present, or video recordings of a facilitator presenting key themes embedded in the tool.
- More visual and interactive elements are preferable to long sections of explanatory text and static diagrams.
- The underlying SD models should be thoroughly tested for performance under extreme variable values to avoid

confusion, and the use of some non-normalised models should be considered. It may be useful to provide a detailed model for a specific coastal resort so that concrete figures and scales can be displayed.

- After giving participants the opportunity to practise bringing the model into a sustainable state, providing the facility for them to view 'pre-cooked' variable combination settings for sustainable scenarios would be a useful teaching device.

Assessment of Effectiveness of the Tool

As discussed in the Evaluation Methodology section, an OL tool is said to be effective if it leads to change, specifically behaviour change. Whilst behaviour change was not explicitly tested in this study, using the assessment frameworks described, there is evidence of *likely* behaviour change in participants in that both their stated intentions (behaviour) and their increased scores in the OL dimensions, are associated with the predictors of change, as shown in **Tables 3**, **4**. Further research could explore the actual effect on behaviour.

Survey Design Limitations and Recommendations

Survey design in this study was kept relatively simple, in that a limited number of questions were used to assess each dimension of the predictors of behaviour change. A more detailed survey could add more questions for each dimension, which would reduce the error associated with a single question (Phal and Wyles, 2017).

It is possible that, since participants were aware that they were participating in a Coastal Tourism OL initiative, this may have influenced their answer toward what was felt to be 'expected' in pre- and post-surveys.

Follow-up surveys, to identify whether participants have undertaken intended behaviours, together with enabling and inhibiting factors, would provide valuable data on long term behaviour change.

The surveys collected data on current behaviour as regards trips to the coast locally and on holidays abroad. The online tool also collected data on participants' location, age, gender, occupation and highest educational qualification. The data for these has not yet been analysed. These factors could be investigated to assess their level of influence on participant's responses and predictors of behaviour change.

Recommendations for Full Study

Results of the pilot study show improvement in OL, Systems Literacy, and likelihood of behaviour change, and are thus encouraging. The tool and teaching methods can be refined according to the qualitative feedback obtained during the initial study, and a full trial conducted with a larger number of participants.

In order to provide evidence that a Systems approach, including interacting with simulations, increases effectiveness (RQ1), use of a control group would help to isolate the effect of this approach from that of other features of the tool. The control group would interact with a tool with similar OL content, but without explicit Systems concepts, nor simulations.

The tool was designed for a general audience for the purposes of the pilot study but would benefit from being designed to suit more closely one of two main groups: policy makers, and general learners such as adults in the community or schoolchildren.

CONCLUSION

This research represents a promising start in the direction recommended by the NMEA (Tran et al., 2010) toward a Systems- and simulation-oriented approach to OL tools. All OL dimensions were increased after use of the tool in the pilot study, some very significantly. A Systems approach could well make OL and sustainability teaching more effective. The theoretical link between the increases in OL dimensions and predicted behaviour change, described in this paper, is also important, given the current urgency for dealing with serious problems with the world's oceans. These results provide motivation for further research. The next step would be to further develop the OL tool and design it for use with policy makers and for the general public, and in education, and to conduct a larger study.

ETHICS STATEMENT

Ethical approval is not required for this research because it does not collect personal information. The data gathered from the survey participants did not contain any information which could identify the individual participant. The information gathered from the participants in-tool included their country at the time of participation, age category, gender, occupation and highest educational qualification. Location, occupation and educational qualification data have not so far been used. The information gathered from the survey included location (town or city) and their responses to questions related to their awareness, knowledge, attitude, communication and behaviour in relation to ocean literacy topics. According to the National University of Ireland, Galway's ethical approval guidelines, this research does not come under an area that requires ethical approval.

The surveys were carried out using paper forms and at the start of the survey each participant was required to agree with the following statement: "This survey forms part of a study being carried out to evaluate the effectiveness of ocean literacy (awareness raising and training) materials developed under the ResponSEAble project. Answers given will remain confidential and only anonymised and grouped data will be used in the analysis and reporting. By taking part in this survey you are consenting to your data being used as part of this study."

AUTHOR CONTRIBUTIONS

CB was the principal author of this manuscript. OM was the secondary author and the leader of the work package under which this research was conducted. MA contributed to evaluation methodology, theory of change and survey design.

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University Extension and Informal Education: Useful Tools for Bottom-Up Ocean and Coastal Literacy of Primary School Children in Brazil

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While increasing awareness about ocean-related topics is a matter of urgent necessity, ocean and coastal-literate schoolchildren are uncommon in Brazil, even in coastal cities. In the present study, we report the activities of an environmental education project spanning a 3-year period in São Vicente, a city surrounded by marine habitats in the southeastern state of São Paulo. This project was part of a university initiative aiming to promote shared knowledge between marine biology student-monitors and the encircling community. With the aid of informal and practical educational activities, we introduced topics of marine zoology, marine ecology, waste management and recycling to 200 fifth-year primary students. Using pre- and post-instructional questionnaires, we evaluated the students' general knowledge of provided ocean and coastal literacy topics. Our results showed a significant difference between initial and final perception across all questions, with a higher questionnaire score after activities. The highest increase in perception concerned lessons on the marine fauna found around the school (94.6% from the initial 7.9%), pointing to the intrinsic value of teaching biological sciences from a zoological perspective. Increased knowledge retention was also observed in lessons on pollution (52.6% from 26.7%), recycling (77.2% from 61.9%), and regional waste treatment (51.8% from 24.2%). Overall, this initiative proved to be a fruitful addition to the school curriculum, especially considering the relevance of rapid urbanization, environmental degradation and water pollution in São Vicente and the role these children might exert as critical-thinking citizens in the future. On the other end, our monitors were also provided with the opportunity for an informal teaching environment complementary to their usual academic-centric degree, with a fresh perspective on accessible scientific communication.

Keywords: university outreach, environmental education, elementary students, marine zoology, recycling

INTRODUCTION

University extension, also known as university outreach, is considered one of the three pillars of higher education institutions in Brazil, a position shared alongside education and research (Brasil, 1988[1]). It can be defined as any educational, cultural or scientific activity that "extends" academic practices to the surrounding community while bringing traditional knowledge into the university, promoting dialogue and generating shared experiences (de Paula, 2013). In this context, projects aimed at complementing gaps in civic education, especially children's, can be a valuable asset to society while offering the opportunity for the development of teaching and communication skills of university students.

The role of environmental education in generating critical-thinking citizens is a topic that gained traction following Rio de Janeiro's 1992 Earth Summit (Rio +20), manifested in the Agenda 21, a major program which established the necessary steps to achieve sustainable development in the 21st century. One of such steps, on Promoting Education, Public Awareness and Training, culminated years later in the Política Nacional de Educação Ambiental (National Policy on Environmental Education); this policy aims to guide both formal and informal teaching of environmental education at all stages, through interdisciplinary practices and support of local and regional projects in Brazil (Brasil, 1999[2]).

In a sciences program, informal learning encompasses activities ranging from visiting museums and attending lectures, to participating in science fairs and competitions (Dib, 1988). However, the idea of learning through play and exploration is an often-overlooked educational feature (Semper, 1990), especially in the classroom environment where a dialectic approach adopting both formal and informal activities still constitutes a recent trend (Marsick et al., 2017). Accordingly, the latest census administered by the Brazilian Ministry of Education shows that only 11.5% of public primary schools in the country are equipped with biology laboratories, with the majority of teachers still relying on traditional textbooks despite the presence of computer labs in almost half of the schools (INEP, 2017[3]).

Teaching individuals about our ocean and coasts is a necessity to ensure sustainable use of their natural and social resources, i.e., a bottom-up approach (McKinley and Fletcher, 2010). This is turn should be accompanied by a top-down strategy of policies and regulations concerning said resources (Mora et al., 2009). Yet, even though the ecological, economic and social value of the ocean has been long postulated (Costanza, 1999), anthropic activities still offer a threat to the maintenance of the marine environment (Lotze et al., 2006; Worm et al., 2006; Andrady, 2011). Such a trend arises from an ocean-illiterate general population (Spruill, 1997; Steel et al., 2005), with formal strategies to communicating ocean science to young people being severely deficient in a number of countries (Cummins and Snively, 2000; Ballantyne, 2004; Guest et al., 2015).

To be implemented until 2020, the Base Nacional Comum Curricular (National Common Curricular Base) is a general policy setting to guide school curriculums of both public and private preschool, primary and secondary institutions in Brazil. According to its guidelines, ocean science is to be taught at grade eight of primary education, as an introduction to ocean circulation (MEC, 2018[4]), with no mentions of marine or coastal environments made over the remainder of the document. While employing knowledge to reduce human impacts on the ocean is at the core of ocean literacy (McKinley and Fletcher, 2010), current education efforts appear to be doing little to advance this paradigm (Guest et al., 2015).

The present study aims to report the activities of an extension program entitled *Pet-mar: using recycled material to teach about marine animals* (Mar is Portuguese for "sea"). This project spanned three years and took place at a public primary school in São Vicente, Baixada Santista metropolitan area, a city with relevant socio-ecological connections to the sea in São Paulo, Brazil (**Figure 1**). With a playful and spontaneous way of teaching, we shared marine zoology, ecology, conservation and recycling concepts with fifth-year public school students. Our aim was to address the importance of the marine environment surrounding the school, the impacts of inefficient waste management policies and how each student could do their part in preserving the ocean for future generations, thus helping produce ocean and coastal-literate citizens.

MATERIALS AND METHODS

The initial contact with the school was established by communicating our proposal to the school coordinator and principal. Once permission was granted, a resident teacher and the school coordinator accompanied all activities, while our team was composed of undergraduates monitored by senior year marine biology students. We taught three classes in 2014 and two classes in 2015 and 2016 each, supervising 200 students aged 10–11 within this time span. We held weekly meetings with the school coordinator and principal, as well as the project coordinator at the university.

Our project underwent three phases. The first phase, executed within the first school semester (March–July), consisted of expositive lessons on zoology and ecosystem ecology, with content supplementary to the school's curriculum and the Plano Nacional de Educação (National Education Plan). The second phase focused on pollution and the societal implications of an inefficient waste management system, also following the curriculum. The final phase had the children in full command of their actions in the form of crafting sessions, which culminated in the confection of marine animals from reused material, i.e., "pets". This term refers to companion animals while also being a wordplay on polyethylene terephthalate

[1]https://www.senado.leg.br/atividade/const/con1988/con1988_18.02.2016/art_207_.asp

[2]http://www.planalto.gov.br/ccivil_03/LEIS/L9795.htm

[3]http://download.inep.gov.br/educacao_basica/censo_escolar/notas_estatisticas/2018/notas_estatisticas_Censo_Escolar_2017.pdf

[4]http://basenacionalcomum.mec.gov.br/abase/#fundamental/ciencias-no-ensino-fundamental-anos-finais-unidades-tematicas-objetos-de-conhecimento-e-habilidades

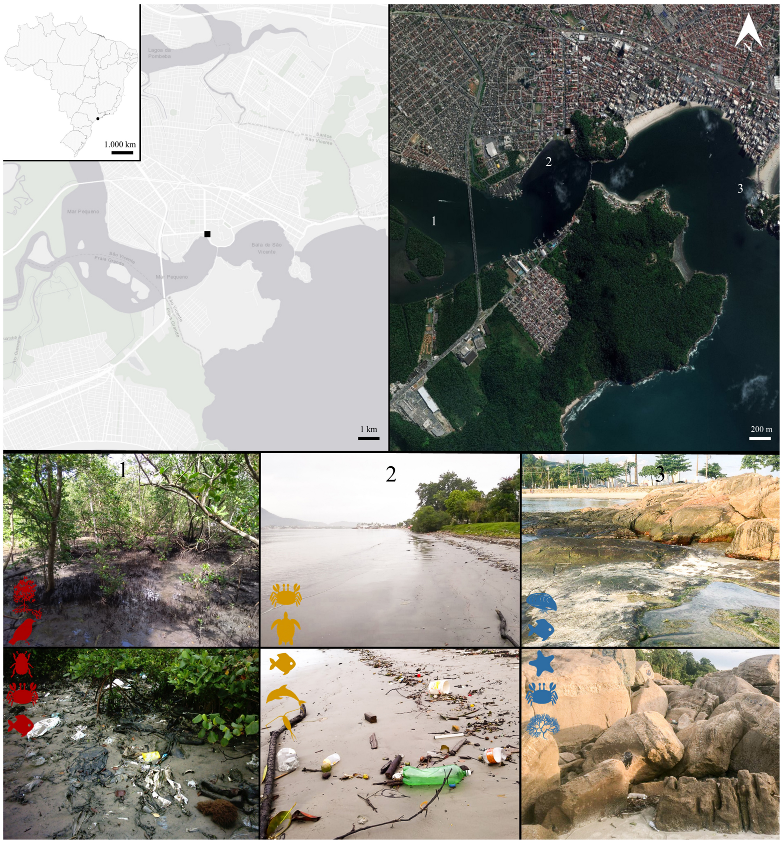

FIGURE 1 | Map of São Vicente (shown as black circle), São Paulo, Brazil, highlighting the school's location (black square) and surrounding coastal and marine habitats which were discussed during the project: mangroves (1), sandy beaches (2), and rocky shores (3). Contrasting states of pollution are show for each habitat (top – clean; bottom – polluted). Main fauna and flora groups explored in our activities are represented as vectors for each habitat (top to bottom). Mangroves (red): mangrove trees, birds, insects, crustaceans and fishes; sandy beaches (yellow): crustaceans, marine reptiles, fishes, marine mammals and zooplankton; rocky shores (blue): mollusks, fishes, echinoderms, crustaceans and algae. All vectors are released under the Creative Commons CC0 License.

(PET), the main component of soft drink plastic bottles. Both second and third phases took place within the second semester (August–December).

Following Resolução #510/2016 (Brasil, 2016[5]), article 1, paragraphs VII and VIII, this study was exempt from ethics evaluation by the Comitês de Ética em Pesquisa/Comissão Nacional de Ética em Pesquisa (Committee for Ethics is Research/National Committee for Ethics in Research). This work was carried out in accordance with and approved by the Comissão Permanente de Extensão Universitária – UNESP (Permanent University Extension Committee). All respective guardians gave written informed consent for children participation and image publication in accordance with the Declaration of Helsinki.

Activities

What Is There?

Our first meeting with the children concerned the meaning of biodiversity and ecosystem. Following this exposition, we presented the students with a sensorial museum: three opaque boxes with a frontal opening big enough for their hands to fit in, but with otherwise indiscernible content save by touch (**Figure 2A**). Each box had a plastic tray filled with (1) mud and leaf detritus, (2) beach sand, or (3) salt water and rocks, mimicking a mangrove, a beach and a rocky shore, respectively. We then asked the students to decide as groups which marine ecosystem was being represented.

Our Surrounding Environment

The second activity took advantage of the school's projector and whiteboard to show how these environments were inserted within the city, and which organisms inhabited each one (**Figure 2B**). We employed satellite images of the area surrounding the school as well as pictures of the fauna more commonly found there to show just how close the children were to those habitats (e.g., mangroves, rocky shores) (**Figure 1**).

Sea Creatures in Land!

The third activity consisted of us showing the children coastal and estuarine specimens from the university's research projects and zoological collection, while inviting participants of another

[5]http://bvsms.saude.gov.br/bvs/saudelegis/cns/2016/res0510_07_04_2016.html

FIGURE 2 | Activities promoted by the project: **(A)** What is in there?; **(B)** Our surrounding environment; **(C)** Sea creatures in land!; **(D,E)** Understanding marine plankton (with main observed phyto- and zooplankton specimens represented inside the white rectangle); **(F)** Think fast and recycle!; **(G,H)** Our marine "pet" workshop.

extension project within our university, the Museu Itinerante de Biologia Marinha (Itinerant Museum of Marine Biology, MIBIM), into the classroom (**Figure 2C**). This was, for the majority of students, their first contact with marine and coastal organisms such as sea urchins, sea turtles and sharks. During this lesson, we asked the students to associate each organism with its most likely environment, thus establishing a link with the previous activity.

Understanding Marine Plankton

Our final lesson for the semester took place outside the classroom at a nearby beach. The children were presented to the concept of (phyto- and zoo-) plankton and its relevance to the marine food web while one of our monitors showed how to collect it (**Figure 2D**). The material was then brought back to campus and displayed on stereomicroscopes, while we showed how to identify the most common organisms (**Figure 2E**). This was the children's first contact with analytic equipment and their first time entering the university.

What Is Pollution and How Does It Affect Us?

Following the initial themes of biodiversity and ecosystems, we adopted a pollution and recycling-oriented approach to second semester classes. The first activity was a lesson on the different types of pollution (e.g., visual, sound) and how each of them affected the environment (e.g., atmospheric smog, plastic entanglement of marine organisms and improper waste disposal in dumps). We then divided students into groups and asked them to mimic specific types of pollution and their effects on the environment. Once again, we stressed how these concepts applied to our surrounding ecosystems (**Figure 1**).

Think Fast and Recycle!

This lesson consisted of a competition in which students had to quickly associate recyclable materials with their standard bin colors (i.e., red for plastic, green for glass, yellow for metal and blue for paper in Brazil) (**Figure 2F**). This activity took place in the sports court located in our campus.

Where Does Our Trash Go?

For our last activity on waste management, we screened the short film Isle of Flowers (Furtado, 1989), which narrates the path of organic material, from harvesting to the dump, drawing a heavy critique of the conditions faced by impoverished communities in Brazil. We then proceeded to discuss the Política Nacional de Resíduos Sólidos (National Policy on Solid Waste) and how little information the children had regarding the destination of their own waste, even in a city with a selective collection program like São Vicente.

This Is Why We Are Right...

We split the students into two groups to debate *how to draw interest into environmental education*. One group defended an emphasis on man-made impacts on the environment and the importance of industrial production to societal development while the other defended an emphasis on conservation and the relevance of pristine environments. We hoped to make them realize this was precisely our project's aim, and both approaches had their merit, especially when juxtaposed.

Our Marine "Pet" Workshop

For the final set of activities, we introduced the third phase of the project. From the start of the project, children were incentivized to save recyclable material such as cartons, bottles, cans, and cardboard boxes. Students then brought these materials to school and we provided them with paper, glue, paint, paintbrush, scissors, etc. We asked the children to create any marine animal from the available materials, and creations took the form of barnacles, corals, octopuses and whales, to mention a few (**Figure 2G**).

Our final meeting had the students present their artwork and give a short summary of the chosen organism. "Pets" were initially put on display for a week in a reserved section of the school before the children took them home (**Figure 2H**).

Survey Design and Distribution

In the final year of our project, the children answered pre (Q1) and post-instructional (Q2) electronic surveys. Both questionnaires were identical and consisted of 10 multiple-choice questions (**Table 1**), encompassing ocean literacy principles five, *The ocean supports a great diversity of life and ecosystems* and six, *The ocean and humans are inextricably* *interconnected* (College of Exploration, 2015[6]), as well as topics concerning waste management in São Vicente. A third, facultative open-answer survey (Q3) applied in conjunction with Q2 inquired students about their favorite (and least favorite) activity throughout the project and suggestions for future activities (**Table 2**).

Data Analysis

We graded the questionnaire out of the previously mentioned 10 questions (Q1 and Q2) with right answers having the same weight. We checked the data for normality and homoscedasticity using Shapiro-Wilk and Levene's tests, respectively. We applied the non-parametric and two-way crossed permutational multivariate analysis of variance (PERMANOVA) considering the period of application of our questionnaire (initial and final) and gender as fixed factors. PERMANOVA is robust for non-normal distributions and univariate analysis applied to Euclidean distance matrices (Anderson et al., 2008; Uribe et al., 2015). The critical level (α) was set at 95% of confidence interval (α = 0.05). Values throughout the text are reported as mean ± standard error.

RESULTS

In total, 63 students took part in Q1 and 58 in Q2 and Q3, with 50.7 and 39.5% identifying as female, 41.2 and 48.2% as male, and 7.9 and 12% as other or choosing not to respond, respectively. Students showed an overall significant change in perception on provided ocean and coastal literacy topics after our activities (PERMANOVA: $F = 3.9717$, $Df = 1$, $p = 0.0041$) independent of their gender (PERMANOVA: $F = 0.61901$, $Df = 2$, $p = 0.5297$) (**Table 3**). Average Q2 score (4.81 ± 0.24) was higher than average Q1 score (4.14 ± 0.24), and answers also varied as the proportion of correct answers among topics (**Table 4**). Highest increase in perception was observed for lessons on regional biodiversity (94.6% correct answers from the initial 7.9%), pollution (52.6% from 26.7%), recycling (77.2% from 61.9%) and regional waste treatment (51.8% from 24.2%). The definition of ecosystem, however, had a lower retention, and lowest across all questions, by the end of the activities (3.6% from 12.7%). As for Q3, the majority of students (98.1%, 53 out of 54) agreed that the project was important to them, with one student answering "partially" (1.9%, 1/54), and that there was no need for structural change (91.3%, 42/46), but no suggestions on what could be changed for those who said "yes" (8.7%, 4/46). Their favorite activity was "Understanding marine plankton" (71.1%, 27/38), followed by "Think fast and recycle!" (13.1%, 5/38), "Our marine 'pet' workshop" (7.9%, 3/38), and theoretical classes in general (7.9%, 3/38). Only four children mentioned their least favorite activity: "Where does our trash go?" (50%, 2/4), followed by "Think fast and recycle!" (25%, 1/4), and theoretical classes (25%, 1/4).

[6]http://oceanliteracy.wp2.coexploration.org/ocean-literacy-framework/principles-and-concepts

TABLE 1 | List of multiple-choice questions asked on Q1 and Q2.

Question
1. What is the best definition of ecosystem?
a. Series of natural landscapes
b. Environmental aspects (air, water, and soil) not yet affected by human action
c. Interaction between organisms and the environment
d. Place where waste reuse takes place
2. What is biodiversity?
a. Ecosystem diversity
b. Variety of life in the planet
c. Number of animal species
d. Ratio between living and dead beings
3. What are some of the ecosystems found in the Baixada Santista?
a. Mangrove, estuary, beach, rocky shore, restinga, and Atlantic Forest
b. Beach, estuary, desert, mangrove, and Atlantic Forest
c. Atlantic Forest, caatinga, beach, estuary, and mangrove
d. Rocky shore, beach, mangrove, desert, caatinga, and Atlantic Forest
4. What animals are commonly found in mangroves?
a. Sea stars, mussels, crabs and dogs
b. Fishes, pigeons, crabs and whales
c. Snakes, rats, cockroaches and cats
d. Crabs, fish, birds, and insects
5. How does the inadequate disposal of household waste affect the environment?
a. It generates pollution
b. It induces species loss
c. It creates an environmental imbalance
d. All of the above
6. What is organic waste?
a. Plant/animal material, or similar to, which is rapidly degraded
b. Plant material which is rapidly degraded
c. Material from domesticated plants/animals, which is rapidly degraded
d. Material destined to recycling
7. What is recyclable waste?
a. All man-made waste
b. Waste from plants/animals
c. Waste that does not decompose
d. Waste that can potentially be used in new ways
8. What is the purpose of selective waste collection?
a. It promotes reuse of all domestic waste
b. It promotes reuse of all industrial waste
c. It promotes reuse of recyclable waste
d. None of the above
9. What is the final destination of the common waste collected by trucks in São Vicente?
a. Sewage-treatment plant
b. Sanitary landfill
c. Ocean
d. The waste in burned
10. What is anthropogenic action?
a. Activity caused by city people
b. Activity caused by country-side people
c. Activity caused by people everywhere
d. Activity caused by people in first-world countries

Correct answers are in bold.

DISCUSSION

Our results show that the project had an overall positive impact on the children's knowledge of marine and coastal environments,

TABLE 2 | List of questions asked on Q3, along with the number of children who chose to answer each question in bold.

Question
1. Did you think Pet-mar was relevant to your studies? **54**
2. Is there anything we can do to improve the project? **46**
3. What was your favorite activity? **38**
4. What was your least favorite activity? **4**

TABLE 3 | PERMANOVA test on differences in students' questionnaire scores across period (initial and final) and gender (male, female, and other/not mentioned) as fixed and orthogonal.

Source	Sum of sqrs	*Df*	Mean square	*F*	*p*
Period	0.33794	1	0.33794	3.9717	0.0041
Gender	0.10534	2	0.05267	0.61901	0.5297
Interaction	−2.4308	2	−1.2154	−14.284	0.6514
Residual	9.785	115	0.085087		
Total	7.7975	120			

TABLE 4 | Results [i.e., proportion (%) of correct answers] from Q1 and Q2.

	Correct answers (%)	
Question	**Q1**	**Q2**
1. Ecosystem definition	12.7	3.6
2. Biodiversity definition	35.5	35.2
3. Regional habitats	45.2	39.3
4. Regional biodiversity	7.9	94.6
5. Pollution	26.7	52.6
6. Organic waste treatment	37.7	35.1
7. Recycling	61.9	77.2
8. Regional recycling	58.1	58.9
9. Regional waste treatment	24.2	51.8
10. General anthropogenic impacts	53.9	60

as well as waste destination in their own city, by either improving or reinforcing their pre-existing notions. Children's feedback also highlights that playful teaching practices supported by didactic materials are powerful tools in ocean and coastal literacy activities. Lower final perception in questions one, two, and three could be due to our approach during the initial stages of the project, which focused primarily on definitions instead of general processes. Additionally, these suboptimal results could have been affected by time-interval selection biases, considering the eight-month period between the first activities and the final questionnaire. A slight loss of perception on question six could similarly be explained by its reliance on a vocabulary-heavy definition, as children (and teachers) become turned off science as it becomes a content-led subject (Alexander and Flutter, 2009). While we must stress the possible perception biases on early and late activities, question four: "regional biodiversity," stands out. An almost 12-fold increase in perception and retention of a topic discussed during the first phase points to the intrinsic enthusiasm elicited by zoology among children in this age group (Ballantyne, 2004; Baram-Tsabari and Yarden, 2007), and how it can promote enduring conceptual understanding. The "sea creatures in land!" and "understanding marine plankton" lessons had the children interact with real organisms and were the two activities immediately related to question four. Indeed, Pugh (2002) argues that, in a zoology class, the crafting of ordinary and uninspiring content into compelling ideas is more efficient at creating fullness of perception than the traditional instructional teaching methods we hoped to avoid throughout this project.

During this three-year period, we dealt with themes pertaining to UNESCO's (United Nations Educational, Scientific and Cultural Organization) Sustainable Development Goal (SDG) 14, "Life below Water." A framework for ocean literacy teaching, SDG 14 aims to promote a behavioral shift toward sustainable exploitation of marine resources and preservation of the Earth's ocean and seas (Santoro et al., 2017). In regard to its (1) cognitive learning objectives, students developed an understanding of basic marine ecology and the threats to ocean systems in the form of pollution, (2) socio-emotional learning objectives were mainly fulfilled by giving the children the opportunity to see how their own impacts on the ocean could be minimized via basic activities such as recycling, and (3) as for behavioral learning, students understood the dependence and intrinsic relationship of their region to the ocean and its attributes. The basis of our ocean and coastal literacy activities, in summary, consisted of teaching about the surrounding habitats and socio-ecological problems of the city. Educational approaches using locally sensitive matters, accordingly, are crucial in promoting more efficient environmental education projects (Jenkins, 2003). As many cities worldwide face similar socio-environmental issues, activities analogous to our project could be important in providing local environment knowledge and bringing the real perception of environment issues to future social actors (Amaral et al., 2014; Santos et al., 2018; Ghilardi-Lopes et al., 2019).

The long history of ocean exploitation in São Vicente dates back to its own foundation, when the need of the Portuguese colonizers for maritime communication dictated the location of the first organized town in the country (Moraes, 2007). From the latter half of the 20th century, coastal agglomerations in southeast Brazil also began to serve as beach resorts, bringing rapid urbanization to the region while invariably causing further degradation of local biomes such as the Atlantic Forest and associated mangroves and restingas (Afonso, 2006). In addition to ecosystem loss, water pollution is an especially critical issue in the São Vicente Estuary, with contaminants ranging from plastic-derived micropellets found in beach sediments (Turra et al., 2014) and local bivalves (Santana et al., 2016), to persistent organic pollutants from domestic sewage and port activities (Bícego et al., 2006). In this case, awareness of one's own environment is a fundamental aspect in leading to societal commitment and actions that promote positive environmental change (Ardoin and Merrick, 2013[7]).

[7] https://nmardoin.people.stanford.edu/sites/g/files/sbiybj4916/f/Grantmakers%2010.6.pdf

Our project was conceived under the urgent need for scientific literacy opportunities in our surrounding community. Accordingly, traditional public ocean literacy efforts in Brazil have been mainly restricted to exhibitions, such as the ones hosted by aquariums (Holanda et al., 2015), and the Programa de Mentalidade Marítima (Maritime Mentality Program) (CIRM, 2018[8]). Over the last 20 years, however, environmental education initiatives dedicated to dialogue promotion within the classroom have become more widespread. The Instituto Curicaca (Curicaca Institute) is one of such organizations seeking to build upon traditional community knowledge of the Atlantic Forest biome in Rio Grande do Sul (Bohrer et al., 2009). Educators in the Graduate Program in Marine Sciences Applied to Teaching at the Federal Institute of Santa Catarina – Itajaí, also seek to inform public school teachers and promote ocean literacy in southern Brazil (Berchez et al., 2016). Similarly, MIBIM employs undergraduate student-monitors to bring zoological collection specimens into the school environment in the Baixada Santista (Freitas et al., 2018). Given that primary students are near-future active citizens with potential involvement in socio-environmental problems, ocean and coastal literacy activities are important tools in providing a wider and more realistic view of those issues (Santos et al., 2018).

Our study shows how informal extension projects such as Pet-mar are a viable option for students interested in following a teaching career, since they offer a fresh perspective on accessible scientific communication (Barzano, 2008). Ocean literacy, in this context, is an ideal point of entry for the non-academic public into the university, while also providing contact with a non-traditional model of environmental education activities. This is especially relevant in a country where only 16.6% of the population between 25 and 34 holds a tertiary education diploma (OECD, 2018[9]), and local ecosystem knowledge is a low priority in environmental education projects (Loureiro et al., 2007). In contrast, recycling, pollution and general biological diversity figure among the top five environment education themes discussed in Brazil (Loureiro et al., 2007). Our project encompassed all of these topics, but future editions could include more interdisciplinary activities focusing on economic and social aspects of environmental education, as well as ways to increase teacher participation in such activities (see McGregor, 2012). Additionally, for some environmental themes our evaluation highlights the need for adapted definitions, closer to children's vocabulary. Finally, our future endeavors ought to focus on even earlier stages of primary education, with integration across all grades.

[8]https://www.marinha.mil.br/secirm/promar

[9]https://data.oecd.org/eduatt/population-with-tertiary-education.htm

AUTHOR CONTRIBUTIONS

GS-S and JP contributed equally to the design and execution of activities during the project, and had an equal participation on the writing of this manuscript. PP supervised activities as school coordinator. TC envisioned the project and supervised its monitors.

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Evaluating Ocean Literacy of Elementary School Students: Preliminary Results of a Cross-Cultural Study in the Mediterranean Region

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A good understanding of the role and function of the ocean seems to be of paramount importance in recent years, constituting the basic tool for the promotion of healthy and sustainable marine environment, and a target area of the 2030 Agenda for Sustainable Development. In this study, the content knowledge of elementary school students (grades 3–6) in regards to ocean sciences issues was examined. A structured questionnaire was administered to 1004 students participating in a cross-cultural study from three Mediterranean countries (Italy, Croatia, and Greece). The results of the study indicated a rather moderate level of knowledge in the total sample, while slight differences were recorded among the three countries revealing common knowledge gains and misconceptions. Rasch analysis was applied to further evaluate the validity of the results, while the influence of certain demographics on students' knowledge level was also investigated. This study concludes with a discussion of the implications on national curriculum development in elementary education level, in order to promote ocean literacy and to ensure protection and conservation of the Mediterranean Sea.

Keywords: ocean literacy, marine science education, elementary school students, content knowledge, cross-cultural study, Mediterranean region

INTRODUCTION

The ocean is the main physical characteristic that defines our planet making the Earth habitable. It covers over 70% of the Earth's surface, produces more than 50% of the oxygen in the atmosphere, regulates weather and climate, supports a great diversity of life and provides food available for people all over our planet (Cava et al., 2005). Despite its role as a part of the Earth's system and its value for human society, the ocean has shown severe signs of change as a result of human activities. Decades of intensive exploitation of marine resources, pollution, coastal urbanization and climate change have led to degradation and even destruction of marine ecosystems, resulting in the deterioration of ocean health and, subsequently, of human health (UNEP, 2001; Giorgi and Lionello, 2008; UNEP/MAP, 2012, 2015). Last WWF Living Blue Planet Report indicates the critical state of the ocean, showing a decrease of 49% in populations of marine organisms between 1970 and 2012 (WWF, 2015). Thus, understanding the ocean is essential to understanding the planet on which we live and, thereby, is essential to its sustainability (Cava et al., 2005).

The Mediterranean Sea, in particular, the largest and deepest enclosed sea on Earth, is one of the most important global biodiversity hotspots since it hosts 7% of the world's marine biodiversity with a high percentage of endemic species (Coll et al., 2010, 2012), though it holds only 0.82% of the global ocean surface (Blondel et al., 2010). This particular ecosystem has been strongly affected by human activities for millennia (Lotze et al., 2011), and therefore it has been suffering from overexploitation and habitat loss long before the Industrial Revolution (Coll et al., 2010). At present, the Mediterranean Sea is characterized as "under siege" (Coll et al., 2012), due to the impacts of multiple human-induced pressures such as urbanization and mass touristic development (30% of world tourism occurs in the Mediterranean Sea per year), overfishing of more than 90% of fish stocks, different types of pollution, and climate change, which crucially altered the Mediterranean Sea environment (UNEP/MAP, 2012; Volosciuk et al., 2016; Fernandes et al., 2017; Garcia-Nieto et al., 2018). Cumulative and synergetic effects of these pressures have led to severe loss of biodiversity along with impacts on biological communities, ecosystem functioning and its capacity to provide essential goods and services to human society (Guidetti et al., 2014).

International initiatives and instruments, such as the International Convention for the Prevention of Marine Pollution from Ships (MARPOL 73/78), the United Nations Convention on the Law of the Sea (UNCLOS, 1982), Rio Declaration on Environment and Development (1992), Jakarta Mandate on Marine and Coastal Biological Diversity (1995), Code of Conduct for Responsible Fisheries (1995), the London Protocol (1996), the Kyoto Protocol (1997), World Summit on Sustainable Development (2002), Earth Summit (2012), the UNESCO Roadmap for Implementing the Global Action Program on Education for Sustainable Development (2014), all reflect humans' attitudes and awareness toward the ocean environment. Similar initiatives and policies have focused particularly on the Mediterranean region. In 1975, the Mediterranean Action Plan (MAP) was adopted and this was the first-ever Regional Seas Program under the United Nations Environment umbrella, followed by the Convention for the Protection of the Mediterranean Sea against Pollution (Barcelona Convention, 1976). Furthermore, all Mediterranean countries are members of the International Maritime Organization (IMO), which is the United Nations body with primary responsibility for international shipping. Several key EU policies are also important for the protection and sustainability of the Mediterranean region, such as the Common Fisheries Policy (EC/170/83), the Habitats Directive (92/43/EEC), the Water Framework Directive (2000/60/EC), the Marine Strategy Framework Directive (2008/56/EC), the Blue Growth Strategy (COM (2012) 494), and the Maritime Spatial Planning Directive (2014/89/EU).

To protect, conserve and sustainably use marine resources, citizens of all ages need to know and understand the connection between man and sea, i.e., to be ocean-literate citizens. Ocean literacy has been defined as "*an understanding of the ocean's influence on you and your influence on the ocean*" (Cava et al., 2005). Beyond understanding, an ocean literate citizen uses ocean knowledge and awareness of ocean issues to communicate about the ocean in a meaningful way and make informed and responsible decisions. To this aim, United Nations has declared a Decade of Ocean Science for Sustainable Development 2021–2030, and Agenda 2030 for Sustainable Development including 17 goals (SDGs) (United Nations, 2017), among which the approval of a stand-alone goal on the ocean (i.e., SDG 14) has been a major achievement for the global ocean community (Santoro et al., 2017b). In 2017, the United Nations convened a high level "Our Ocean" conference to support the implementation of SDG 14. One outcome of this conference was an inter-governmentally agreed declaration "Call for action" of whose Article 13a reads as follows: "*Support plans to foster ocean-related education, for example as part of education curricula, to promote ocean literacy and a culture of conservation, restoration and sustainable use of our ocean*", hence emphasizing the importance of ocean literacy. To successfully achieve SDG14, ocean-literate and therefore engaged citizens, from the general public to scientists and decision-makers, are needed. Consequently, promotion of ocean literacy in elementary and secondary education is vital (Visbeck, 2018), as children represent the future citizens and consumers, who will develop attitudes and make decisions that will inevitably affect the environment. Children are also important agents of social change in society, because apart from performing responsible environmental behaviors themselves directly, they also have the potential to bring about change by influencing the environmental knowledge, attitudes and behaviors of peers, family and of the wider community (Hartley et al., 2015).

Unfortunately, national school curricula worldwide lack ocean literacy-related issues (Visbeck, 2018), and in some cases, as in New Zealand, they do not even include the word "ocean" (Gough, 2017). Furthermore, coastal and marine topics are almost absent in Science and Geography curricula in different countries such as United Kingdom and Canada, while limited reference to related issues is also evident in Brazilian, Chinese, and Australian curricula (Gough, 2017). Lately, an Ocean Education Curriculum was also created in Japan (Ocean Policy Research Foundation, 2011) in order to promote ocean education in elementary and secondary education. Universities also lack ocean literacy-oriented training programs (Visbeck, 2018), while the absence of ocean topics, particularly in teacher preparation programs, is evident (Payne and Zimmerman, 2010).

Although the ocean practically defines our planet, relative knowledge still appears inadequate (The Ocean Project, 2009; Gelcich et al., 2014; Chen and Tsai, 2015; Guest et al., 2015;

Mogias et al., 2015). This lack has been evidenced since the birth of marine education in mid 1970s, with the definition itself of "Marine and Aquatic Education" (Goodwin and Schaadt, 1978), a forbearer of ocean literacy, and of the first academic studies in this field (e.g., Fortner and Wildman, 1980; Fortner, 1985; Fortner and Lyon, 1985). After these pioneering investigations, marine education and related topics have been addressed by numerous surveys carried out among different target groups, and spanning from the general public to students as well as their teachers. Analysing the literature, some large surveys have addressed the knowledge of the general public mostly in the United States and Europe; most of these studies have shown people to be concerned about pollution, industrial toxic waste, and overfishing, but to have poor knowledge of other ocean issues (e.g., ocean acidification), and little trust in individual action, despite the positive attitudes toward behavioral changes for the sake of ocean environment (e.g., Belden Russonello and Stuart, 1999; Steel et al., 2005; Fletcher et al., 2009; The Ocean Project, 2009; Gelcich et al., 2014; Perry et al., 2014; Capstick et al., 2016). A few published surveys on pre- and in-service teachers have revealed a rather moderate knowledge of ocean science (e.g., Boubonari et al., 2013; Mogias et al., 2015; Dromgool-Regan et al., 2017; Hartley et al., 2018). Published research on the knowledge of ocean issues among college and university students from different countries (e.g., United States, Taiwan, China, Australia) is also scarce, revealing moderate knowledge (Ballantyne et al., 2005; Cudaback, 2006; Chen and Tsai, 2015; Danielson and Tanner, 2015; Umuhire and Fang, 2016). On the contrary, most of the studies focusing on the knowledge of the ocean environment have been performed on elementary and secondary school students, mostly in the United States (e.g., Brody and Koch, 1986; Fortner and Mayer, 1989; Brody, 1996; Rodriguez-Martinez and Ortiz, 1999; Ballantyne, 2004; Lambert, 2006; Plankis and Marrero, 2010; Guest et al., 2015). Further to the above, learning activities and school programs have also been investigated through interventional studies, revealing students' knowledge improvement, especially after first-hand experiences on ocean-related topics (e.g., Fortner and Teates, 1980; Fortner, 1985; Cummins and Snivelly, 2000; Lambert, 2005, 2006; Stepath, 2007; Plankis and Marrero, 2010; Hartley et al., 2015, 2018).

The aim of the present study, which constitutes the first cross-cultural attempt at the elementary school level, is two-fold: (a) to evaluate and compare students' knowledge about ocean sciences issues according to the ocean literacy framework, and (b) to examine for possible common misconceptions among three Mediterranean countries. The present study illustrates the level of students' ocean literacy on a sub-regional level, and provides guidance for a more focused and sound design, development, and implementation of marine-friendly curricula in terms of elementary school courses and textbooks, in-service teacher training, and pre-service teacher preparation programs.

The Ocean Literacy Framework

Ocean literacy has received increased attention in recent years (e.g., Steel et al., 2005; Buckley et al., 2017), while the interest on issues related to marine education and the aquatic environment has its roots in the environmental movement of the 1960s and 1970s (Marrero and Moore Mensah, 2010). Consequently, the need for marine and aquatic education had already been underlined and studied since the early 1970s (e.g., Charlier and Charlier, 1971; Schweitzer, 1973; McFadden, 1973; Goodwin and Schaadt, 1978; Fortner and Wildman, 1980; Madrazo, Jr., and Hounshell, 1980; Picker, 1980; Dresser and Butzow, 1981; Rakow, 1983/1984; Picker et al., 1984; Fortner, 1985; Fortner and Lyon, 1985). However, it was marginalized and reborn as an official ocean literacy movement in 2004 in the United States. After an extensive process of continuous meetings and constructive discussions, ocean literacy was defined as "an understanding of the ocean's influence on you, and your influence on the ocean," (Cava et al., 2005), and two documents comprising the Ocean Literacy Framework, were developed: a) the Essential Principles and Fundamental Concepts of Ocean Sciences (National Oceanic and Atmospheric Administration [NOAA], 2013), which represent the major ideas that high school graduates should know and understand about the ocean and its significance in the earth system, and b) The Ocean Literacy Scope and Sequence (National Marine Educators Association, 2010), which provides information and guidance as to what students need to comprehend in different grade bands in order to achieve a full understanding of the seven ocean literacy principles and their concepts.

These guidelines, developed to help implement an ocean-dedicated curriculum in the United States, are now largely accepted and have been an inspiration for several initiatives worldwide (Fauville et al., 2018). The U.S. National Science Foundation has invested more than $40M for a 12 year period in a network of Centers for Ocean Sciences Education Excellence, and the European Union (EU) invested more than €7 M in two large international ocean literacy-dedicated projects, SeaChange and ResponSEAble (Fauville et al., 2018). Furthermore, the EU, United States, and Canada signed a transatlantic ocean research alliance that identifies ocean literacy as one of the key areas for cooperation among marine scientists (Costa and Caldeira, 2018). New professional organizations and networks, similar to the U.S. National Marine Educators Association (NMEA), have emerged, including the International Pacific Marine Educators Network (IPMEN), the European Marine Science Educators Association (EMSEA), the Canadian Network for Ocean Education (CaNOE), and the Asia Marine Educators Association (AMEA).

In 2015, a group of researchers and educators from the Mediterranean region (forming the EMSEA Med working group) started an effort to adapt them to the specificities of the Mediterranean Sea. As a result of this procedure, the Mediterranean Sea Literacy (MSL) guide was developed consisting of 7 principles and 46 concepts which describes different aspects of the Mediterranean Sea and its connection to people and society (Santoro et al., 2017a; Realdon et al., 2018). The goal of the MSL guide is to provide basic fundamental knowledge about the Mediterranean Sea to educators, teachers, scientists, Non-Governmental Organizations, blue business sector and policymakers, thus help to achieve awareness, and therefore a blue and sustainable Mediterranean region at all levels of society.

MATERIALS AND METHODS

Participants

A cross-cultural study was conducted to a group of elementary school students from three European countries located on the coasts of the Mediterranean Sea, namely Italy, Croatia, and Greece (**Figure 1**). Our research employed a convenience sampling method with the constraint that participants fit into groups stratified by grade level. Third to 6th-grade students from 20 schools and 17 cities, located in north-western and north-eastern Italy, central coastal Croatia, and northern and southern Greece, comprised the final sample (**Figure 1**), while special attention was paid to obtain similar percentages of gender representation. As a result, the final sample was comprised of 1004 students; forty-eight percent of the participants were females.

Instrument

For the needs of the present study a structured questionnaire to investigate knowledge related to ocean sciences issues was developed taking into consideration previous research (Greely, 2008; Mogias et al., 2015; Fauville et al., 2018), and following the guidelines of the seven essential principles of the Ocean Literacy Framework (National Oceanic and Atmospheric Administration [NOAA], 2013) and the Ocean Literacy Scope and Sequence (NMEA, 2010), which actually provides the guidelines for what it should be taught in certain grade bands. More specifically, the questionnaire contained a set of demographic and sixteen multiple choice questions targeted in certain principles of the framework (**Table 1**). Demographics highly supported anonymity of the participants, and the non-sensitive collected data from the three EU countries (Italy, Croatia, and Greece) cannot be rated as "personal data," according to EU General Data Protection Regulation (EU 679/2016, article 4, paragraph 1); therefore an ethics approval was not required as per applicable institutional and national guidelines and regulations. The items of the knowledge scale were close-ended, making the instrument easy to use, code, and score for statistical purposes. Each correct answer received a value of 1 and incorrect a value of 0; therefore, the score could vary between 0 and 16 (mean value 8.5 portrays the balance point of the scale). Lower scale scores indicated lower student knowledge and *vice versa*. All items consisted of three well distinct distractors, considering the young age of students, and common for all countries except for items 5 and 7 which used region-specific wording; in the former case, the name of each country was referred and in the latter, the Tyrrhenian and the Adriatic Seas were used for the Italian sample, the Adriatic alone for the Croatian, and the Aegean Sea for the Greek sample, respectively.

TABLE 1 | Alignment of the survey questions with the seven essential principles of the Ocean Literacy Framework.

Ocean literacy essential principles	Questions
1. Earth has one big ocean with many features	1, 7, 13
2. The ocean and life in the ocean shape the features of Earth	2, 10
3. The ocean is a major influence on weather and climate	5, 11
4. The ocean makes earth habitable	3, 8
5. The ocean supports a great diversity of life and ecosystems	4, 9
6. The ocean and humans are inextricably linked	12, 14, 16
7. The ocean is largely unexplored	6, 15

FIGURE 1 | Sampling locations of the three Mediterranean countries participating in the study.

The original survey was first developed in English as a common language among the researchers, and then the national versions were written in Italian, Croatian, and Greek languages using translation and back translation (Brislin, 1970). It was examined for content validity in terms of content clarity, language, and difficulty, and also the extent to which the items truly represented basic concepts of ocean literacy principles, by a panel of marine scientists and marine educators. Furthermore, a team of four in-service teachers assigned the corresponding grades 3–6 from each country with a minimum of 5 years of classroom experience was asked to point out the items they did not fully understand; thus their comments were taken into consideration and led to modifications, mainly of the wording. In an effort to further validate the instrument, students' responses were evaluated using the Rasch model for dichotomous items. The family of Rasch models, based on the original ideas and theory of Rasch (1960), has been widely employed for the psychometric evaluation of assessment instruments in science education (Boone and Scantlebury, 2006; Boone et al., 2011, 2014). The main outcome of a Rasch analysis is a unidimensional line or continuum along which test items and persons are located according to their difficulty and ability measures, respectively. Ability is used here as a generic term to indicate the level of achievement of a person on a particular test in a particular area. The response patterns observed on the test items are examined against the model requirements, which include latent monotonicity, local independence, unidimensionality and specific objectivity (e.g., see Wilson, 2004; Bond and Fox, 2007, for an introduction to Rasch analysis). Rasch models are compatible with fundamental measurement (Boone et al., 2011) and offer certain advantages as construct validation tools (Baghaei, 2008). In particular, the dichotomous Rasch model, is one of the dominant models for analyzing binary items (e.g., success/failure) in psychometrics. Rasch analysis was conducted separately on the data of each country, using the R-package eRm (Mair and Hatzinger, 2007; see **Figures 2–4**). The person-item-map displays the distribution of person parameters across the latent construct (questionnaire) in association with item difficulty parameters. This shows whether the distribution of person parameters is approximately normally distributed and it allows investigating whether the items are distributed across the whole spectrum of the latent construct. **Figures 2–4** display the person – item maps for the three countries (Italy, Croatia, and Greece, respectively). The distribution of person

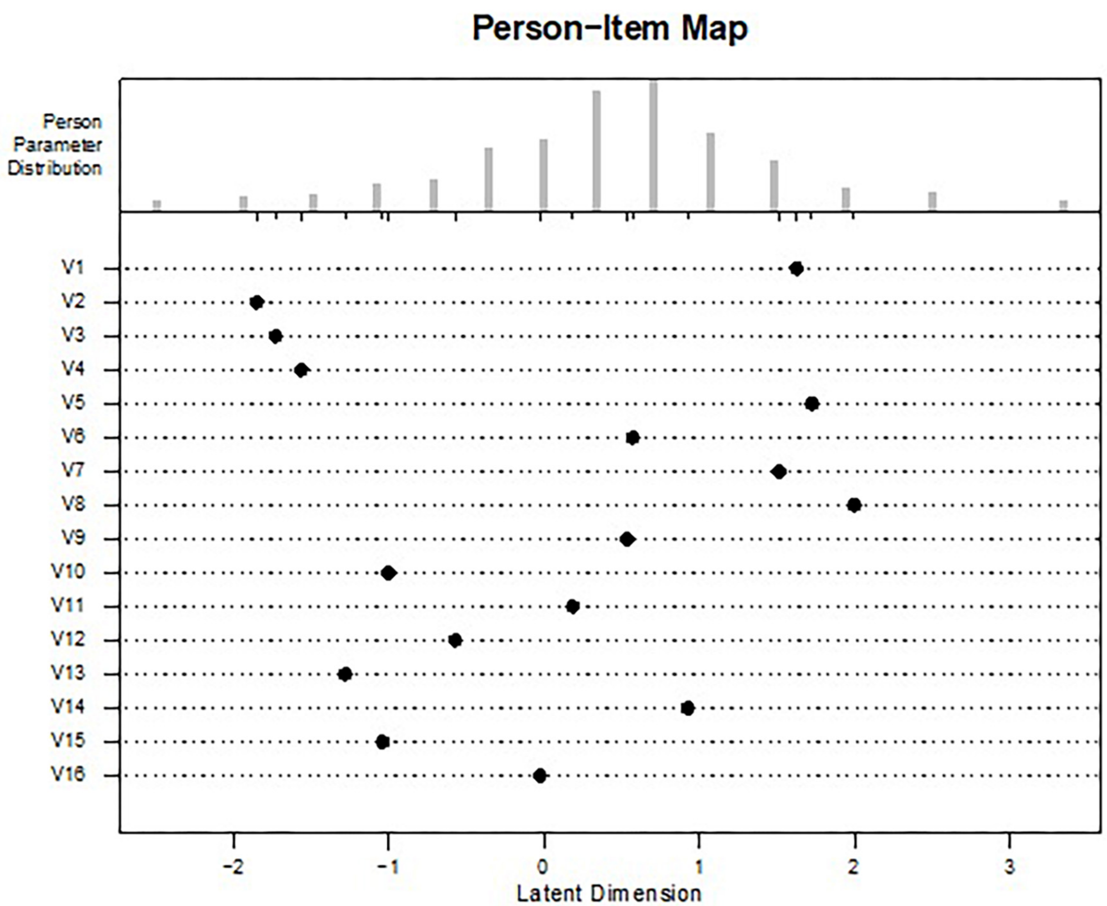

FIGURE 2 | Person-Item map for Italy.

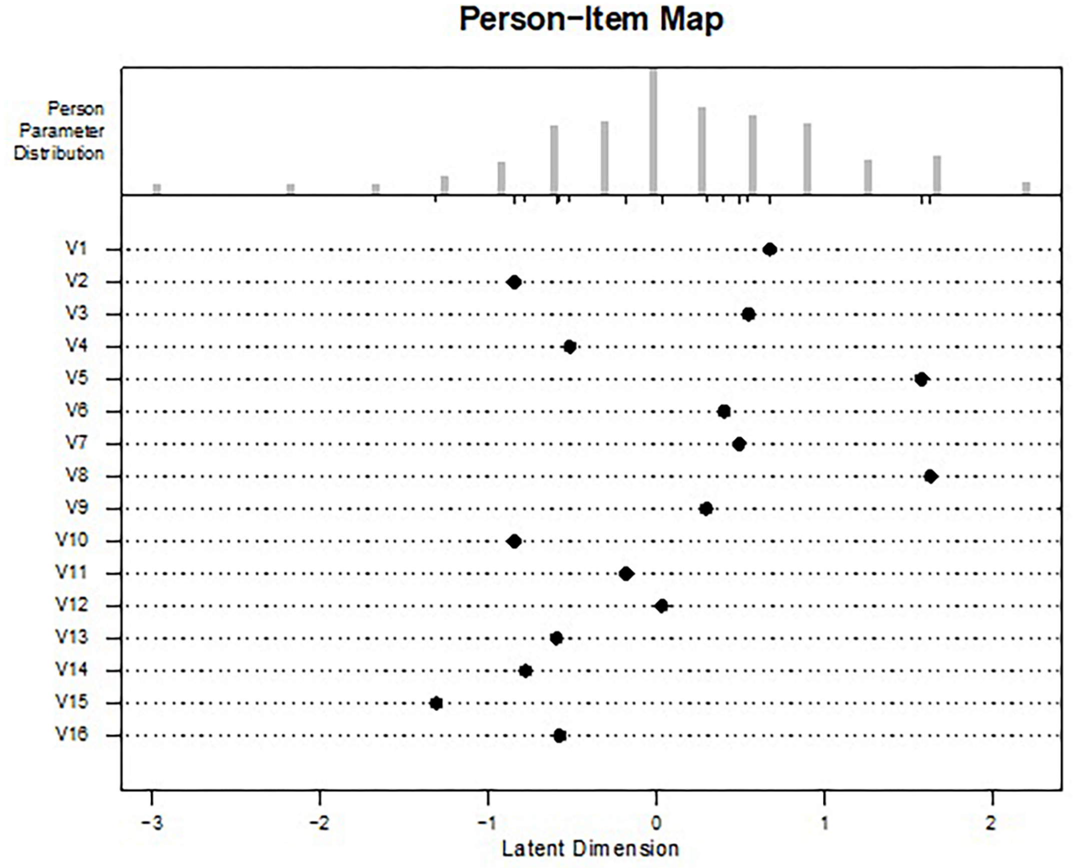

FIGURE 3 | Person-Item map for Croatia.

parameters is approximately normal for all three countries. In the case of Italy items are distributed across the whole spectrum of the construct indicating that the questionnaire is well suited for the specific student population, while in the case of Croatia and Greece the instrument appears to be not that well suited for students of lower ability levels. The analysis revealed that item separation reliability for each subscale was rather low (0.4638, 0.4202, and 0.5292 for Italy, Croatia, and Greece, respectively), and therefore the item estimates are to be interpreted conservatively. Even though the item separation reliability was proved to be lower than expected, there are points of great interest in terms of the relative difficulties among the response categories, which constitutes the actual scope of the paper.

Background Factors

The questionnaire also included questions about students' gender, grade level, participation in any kind of nature-related activities, and use of television documentaries as the main information source about general environmental issues.

Data Collection and Analysis

Prior to the administration of the survey instrument, participants were informed about the purpose of the study and the voluntary basis of participation from their classroom teachers. Moreover, the researchers from all three countries ensured the official approval of the participating schools' principals to administer the questionnaire, while written and informed consent was obtained from the parents of all participants in Italian and Croatian schools, and oral and informed consent was obtained from the parents of all participants in Greek schools for participation in this study; both consent procedures followed were in accordance with applicable institutional and national guidelines and regulations. Questionnaires were administered in the classroom in February–June and September–October 2018. Completion time ranged between 20 and 30 min.

Data analysis involved the following two steps. As this was the main focus of our study, in the first step descriptive statistics were applied to portray frequencies and knowledge scores of the participants as a whole and for each country separately, with regard to certain grade levels. The second step referred to the use of *t*-tests and one-way analyses of variance (ANOVA) to assess the effects of background variables on students' knowledge as well as possible differences among the three sample sub-groups. Statistical analyses were performed with the use of the Statistical Package for Social Sciences (SPSS v. 21); for all statistical tests, the

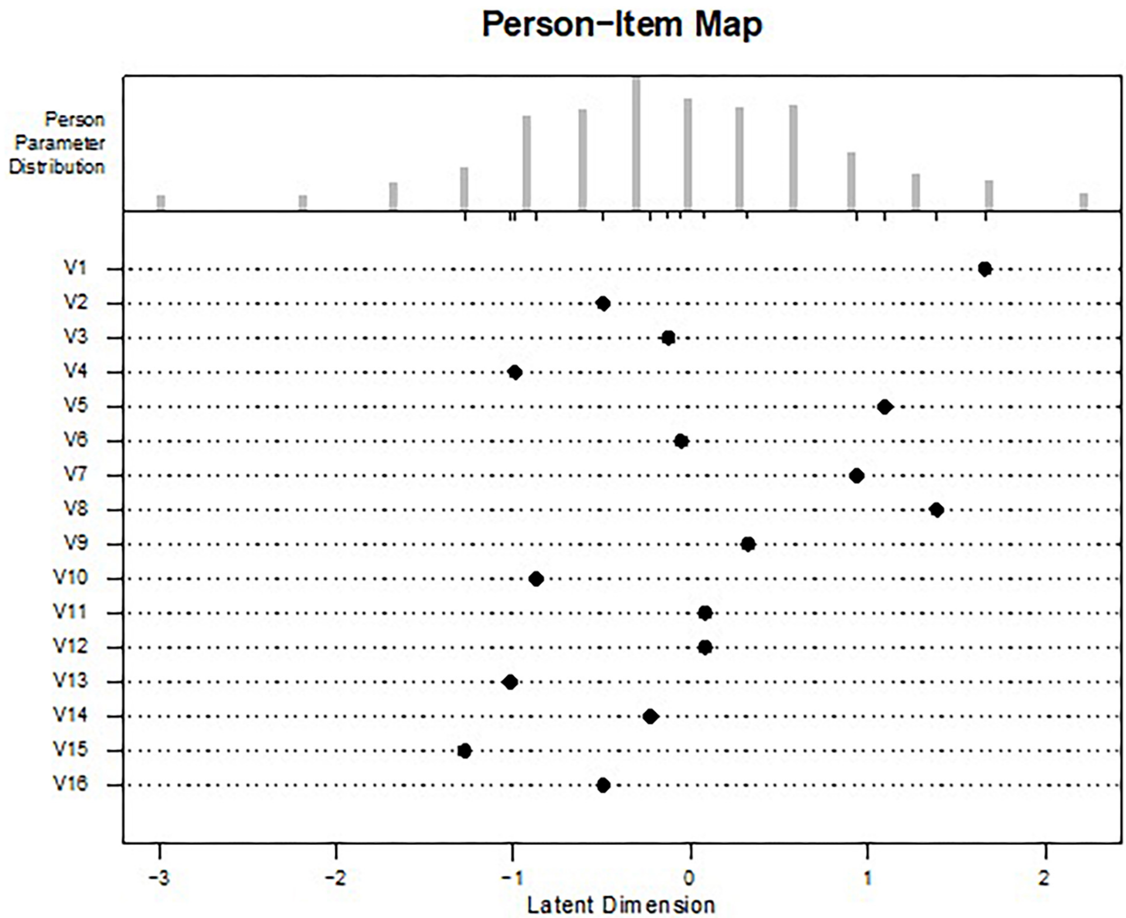

FIGURE 4 | Person-Item map for Greece.

significance level was predetermined at a probability value of 0.05 or less.

RESULTS

Background Data

From the 1004 students comprising the total sample in the present study, 41.2% resulted from Greece, 35.1% from Italy, and 23.7% from Croatia. The percentages of participation recorded for each grade level were 12.4% for grade 3, 31.8% for grade 4, 30.2% for grade 5, and 25.7% for grade 6, respectively. Detailed sample characteristics per country and grade level are given in **Table 2**. The majority of the students grew up in a coastal hometown environment, as their schools seem to be in an immediate vicinity to the sea, few were located at a slightly bigger distance (between 5 and 25 km), while students of two Greek cities and one Italian, consisting 25.1% of the total student sample, were located in a distance larger than 30 km far away from the nearest coast; moreover, only 7.6% of the participants, coming exclusively from a Greek city, had a direct access to a marine institute and an aquarium. Furthermore, 75.5% of the students argued that they had already taken part in some kind of nature activities in their schools,

TABLE 2 | Sample characteristics of the participating countries per grade; y.o. stands for years-old.

Country	Gender		Grade 3 (8–9 y.o.) (*n* = 124)	Grade 4 (9–10 y.o.) (*n* = 319)	Grade 5 (10–11 y.o.) (*n* = 303)	Grade 6 (11–12 y.o.) (*n* = 258)	Total (*n* = 1004)	Schools (n)	Cities (n)
	Males (*n* = 522)	Females (*n* = 482)							
Italy	189 (53.7%)	163 (46.3%)		152 (43.2%)	136 (38.6%)	64 (18.2%)	352 (35.1%)	12	11
Croatia	127 (53.4%)	111 (46.6%)	91 (38.2%)	48 (20.2%)	5 (18.9%)	54 (22.7%)	238 (23.7%)	2	1
Greece	206 (49.8%)	208 (50.2%)	33 (8.0%)	119 (28.7%)	122 (29.5%)	140 (33.8%)	414 (41.2%)	6	5

while almost 60.0% of them claimed to have made use of television documentaries as the main information source for general environmental issues.

Ocean Content Knowledge

Elementary school students were found to possess a rather moderate level of ocean sciences content knowledge exhibiting scores slightly above the balance point (8.53/16), ranging between 7.78 (±2.557) for the Greek sub-sample and 9.18 (±2.223) for the Italian one. **Table 3** shows the frequencies of correct answers per country and question. More specifically, the mean correct values were 57.4, 54.0, and 48.6% for Italy, Croatia, and Greece, respectively; identifying a cut-off limit of 70% of correct answering, 7 out of 16 questions for the Italian students were met, four for the Croatian, and three for the Greek students; while no significant difference was detected among the three sub-samples in six out of the total 16 questions (items 5, 6, 8, 9, 15, and 16), *post hoc* analysis revealed a statistically significant difference among all three countries only in four questions (items 1,2,3, and 14), indicating in some extent similarities in both knowledge gains and misconceptions (**Table 3**).

TABLE 3 | Relative frequencies of correct answers, and *p*-values per question among the three countries (bold letters indicate high similarities).

Question	Italy (*N* = 352)	Croatia (*N* = 238)	Greece (*N* = 414)	*p*-value
1	24.1	38.2	16.2	0.000
2	89.5	72.7	59.4	0.000
3	88.4	41.2	51.0	0.000
4	86.6	66.0	70.0	0.000
5	**22.4**	**20.6**	**24.9**	0.435
6	**46.6**	**44.5**	**49.3**	0.486
7	**26.1**	42.4	**27.8**	0.000
8	**18.2**	**19.7**	**20.0**	0.795
9	**47.4**	**47.1**	40.6	0.109
10	79.3	72.7	67.6	0.001
11	**55.7**	**58.4**	46.1	0.003
12	71.9	53.4	46.1	0.000
13	83.2	**67.6**	**70.5**	0.000
14	38.4	71.4	53.4	0.000
15	**79.8**	**80.7**	**75.4**	0.187
16	**60.5**	67.2	**59.4**	0.123
mean	57.4	54.0	48.6	

Furthermore, the ordering of the knowledge items from Rasch Analysis demonstrated in **Table 4** showed an interesting pattern of responses among the three countries. Items at the base of the scale implied the most difficult ones, while those at the top of the scale indicated the easiest ones to correctly answer. This item placement in the scale clearly revealed that students presented, with some variations among the three countries, greater difficulty in identifying that oxygen originates mainly from the ocean (question 8); all sub-samples managed to give correct answers in very low percentages, hardly ranging between 18 and 20%, while almost two thirds of them clearly chose woods and meadows as the main source of oxygen. Question 5 concerned knowledge about the global water cycle and the origin of evaporated water; all students misplaced the correct answer, namely the warmer seas far away from the participants' temperate countries, in the last position with frequencies varying between 20 and 25%, as they presented the nearest seas as their first choice and the land after a rain as their second one. Another very difficult item was proven to be the first one, pertained to the connectedness of the global ocean; students commonly disregarded the ability for a boat to hypothetically reach every oceanic basin, by presenting high preference for the nearest Atlantic Ocean. Question 7 was very close to that item, as the majority of students confirmed their ignorance of the one and only interconnected ocean by responding that the Aegean Sea for the Greeks, the

TABLE 4 | Item difficulty (in logits) obtained via Rasch Analysis on the data of each country.

	Italy	Difficulty (logits)	Croatia	Difficulty (logits)	Greece	Difficulty (logits)
Easy Items	Q2	−1.851	Q15	−1.310	Q15	−1.276
↑	Q3	−1.73	Q2	−0.845	Q13	−1.017
	Q4	−1.565	Q10	−0.845	Q4	−0.992
	Q13	−1.282	Q14	−0.780	Q10	−0.873
	Q15	−1.040	Q13	−0.595	Q2	−0.494
	Q10	−1.003	Q16	−0.575	Q16	−0.494
	Q12	−0.573	Q4	−0.516	Q14	−0.231
	Q16	−0.027	Q11	−0.181	Q3	−0.127
	Q11	0.184	Q12	0.033	Q6	−0.055
	Q9	0.533	Q9	0.296	Q11	0.080
	Q6	0.570	Q6	0.402	Q12	0.080
	Q14	0.925	Q1	0.674	Q9	0.323
	Q7	1.515	Q7	0.491	Q7	0.935
	Q1	1.625	Q3	0.545	Q5	1.094
↓	Q5	1.724	Q5	1.576	Q8	1.387
Difficult items	Q8	1.997	Q8	1.630	Q1	1.661

Tyrrhenian and the Adriatic for the Italians, and in lower extent the Adriatic Sea for the Croatians are all connected solely to the Mediterranean Sea and not the rest of the seas worldwide (**Tables 3**, **4**).

Contrary to these difficult to answer items, questions 2, 4, 10, 13, and 15 were generally easy for the students to answer. More specifically, the majority of the participants were able to easily identify that ocean research is a basic prerequisite for its protection, that fish fossils, wherever met on land, were formed sometime during the past in the sea, that the ocean hosts a great diversity of life in different parts of its vast volume, that the coastlines are continually been shaped by sea water motions, and that most of the earth's water occurs in the seas and the oceans (**Tables 3**, **4**).

On a grade level basis, although the values slightly varied among the three countries, a rather similar progression pattern in the knowledge level was detected for Croatia and Greece, while this was not the case for Italy (**Figure 5**). More specifically, in the former case a small decrease in grade 4 and a progressive increase in scores during grades 5 and 6 was illustrated; for the Greek sub-sample, this score progression appeared to be more intensive. On the other hand, the Italian sample revealed a slight gradual decrease in scores with progressing in grades. The mean score values among grade levels are also given in **Figure 5**.

Relationships Between Knowledge and Background Factors

In the total sample, male students demonstrated slightly higher knowledge level (mean score: 8.56 ± 2.540) than female students (8.38 ± 2.377) but no statistically significant difference was observed [$t(1002) = -1.193$, $p = 0.233$]; while the Italian and Greek sub-samples showed similar trends regarding gender, Croatian female students revealed higher knowledge scores, but with no statistically significant difference as well. Students who had participated in some kind of nature-related activities within their formal school settings revealed significantly higher mean scores (8.66 ± 2.453) in comparison to students with no such experience (7.91 ± 2.414) [$t(1002) = 4.163$, $p = 0.000$]; this was exactly the case for each country separately. Moreover, students who used to make use of TV documentaries for obtaining environmental information also demonstrated significantly higher knowledge scores in the total sample (8.84 ± 2.401) compared to the others (7.96 ± 2.462) [$t(1002) = 5.619$, $p = 0.000$]; no statistically significant difference was recorded in the Croatian sub-sample in particular.

On a country basis, it appears that there was a significant difference among Italy, Croatia and Greece (9.18 ± 2.223, 8.64 ± 2.314, and 7.78 ± 2.557, respectively) [$F(2, 1001) = 33.656$, $p = 0.000$], while *post hoc* analysis revealed three distinct groups, corresponding to the three countries under study. One-way analysis of variance was also applied on a grade basis, where no significant difference was found among the grade levels [$F(3, 1000) = 0.722$, $p = 0.539$]. Possible relationships between coastal and non-coastal hometown participants' knowledge within each country separately were investigated; Croatia was not included in this analysis as the participating schools were all from the same coastal city. For the Italian case, results revealed that there was a significant difference among students' locations [$F(17, 334) = 2.910$, $p = 0.000$], showing a trend that schools closer to the coast seem to demonstrate rather higher scores; no such pattern was observed in Greece since some inland cities presented higher knowledge scores than some coastal ones. Finally, mean score differences were examined between schools with direct access to a marine institute and an aquarium and schools with not such access; with mean values 9.84 (±2.281) for the former case and 8.36 (±2.445) for the latter, a statistically significant difference [$t(1002) = 5.098$, $p = 0.000$] is apparent in favor of the students who have accessibility to these non-formal educational settings.

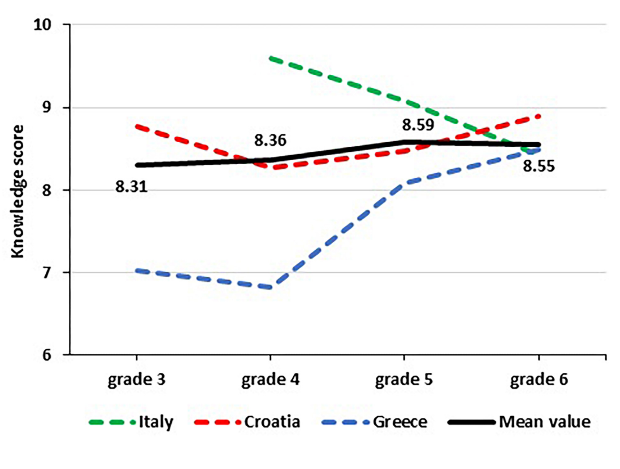

FIGURE 5 | Knowledge scores for each country, and mean values per grade level.

DISCUSSION

In the present study, elementary school students (grades 3–6) of three Mediterranean countries, i.e., Italy, Croatia, and Greece which together cover almost 65% of the total Mediterranean coastline, were found to possess rather moderate knowledge of ocean sciences issues, holding also some misconceptions. The majority of the participants was located in coastal areas and drew on their ocean content knowledge mainly from school environmental activities and TV documentaries. More specifically, the Italian students turned up to have a relatively higher ocean-related knowledge level than the rest of their counterparts, but with a slightly decreasing trend in higher grades. This was not the case for the Greek students who although appeared less knowledgeable among the three countries, their ocean-related knowledge increased progressively with higher grades; Croatian students followed a rather similar to the Greek's pattern. Our findings, in terms of students' knowledge level seems to be in line with studies from other countries (e.g., United States, United Kingdom, Mexico, Canada, South Africa, and Korea) focusing on similar school grades (Brody and Koch, 1986; Fortner and Mayer, 1989; Brody, 1996; Rodriguez-Martinez and Ortiz, 1999; Cummins and Snivelly, 2000; Ballantyne, 2004;

Kim et al., 2013; Hartley et al., 2015, 2018). To the best of our knowledge, only a study from Taiwan evidenced a high level of correct answers concerning knowledge of the marine environment (Wen and Lu, 2013). It should be noted though that most of these studies investigated students' knowledge only as a part of assessments addressing also attitudes and often behaviors. Moreover, and probably due to the relative novelty of the ocean literacy framework, only a few studies have investigated specifically the knowledge concerning ocean literacy principles; Wen and Lu (2013) addressed only some of them, while Fauville et al. (2018) investigated students aged 16 and older.

Participants' rather moderate knowledge could be attributed to the fact that ocean sciences do not constitute a basic part of the educational system in Italian, Croatian, and Greek national curricula, as well as in most European Countries. More specifically, although there is no official reference to the sea in Italian elementary school science curricula, revealing a gap which is covered in some extent by the geography curriculum, sea-related topics are present in elementary school textbooks and therefore probably addressed by most teachers. The Croatian elementary school science curriculum seems to be much more sea-oriented as it foresees an environmental education approach to water and sea, with specifications about water and life, water cycle, coastal landscape, and the Adriatic Sea. According to the Greek curriculum, among the topics addressed in primary school textbooks, marine ecosystems and human influence on the sea can be found along with a superficial and fragmented mention of ocean and regional seas characteristics. In any case, initiatives, originating from Environmental Education Centers and from teachers with remarkable enthusiasm in running environmental education programs, are present in all three countries under study, but they cannot actually meet the needs for a meaningful ocean education.

A rather interesting finding is the fact that the majority of students seemed to share the same difficulty in answering certain questions, and at the same time they showed the same efficacy in correctly answering others, indicating cross-cultural similarities in both knowledge gains and the existence of common misconceptions. Some of the wrong perceptions emerged from this study can be described as true misconceptions for being shared by a large percentage of the students under the present study, but also emerged in others researches and academic catalogs. Misconceptions, or "*ideas that are at variance with accepted views*" (Fisher, 1983), are not simple mistakes due to ignorance; they are extremely widespread within science (and non-science) subjects so that to be considered a universal trait among children, teenagers and, to some extent, adults. Ocean sciences and ocean literacy are no exceptions.

The most difficult question concerned the origin of atmospheric oxygen, in which less than 20% of students answered correctly, which was the ocean and not the widely chosen woods, meadows or the tropical forests. Brody and Koch (1986) evidenced a similar difficulty in a sample of students from Maine (United States). This topic, including the primordial origin of O_2 in earth's history, also resulted very hard to answer for students older than 16 years (Fauville et al., 2018). The misconception about the origin of atmospheric oxygen also emerged in a highly cited list of Earth science misconceptions compiled by Phillips (1991) and is quoted among the "Ten Forest Myths" by Cook (2018).

Two other questions with low levels of correct answering were those about the connectedness of all seas in one single and united water mass, revealing a misconception in elementary grades, namely the inability to perceive the connectedness of all seas in one single water mass, which appears only marginally to be addressed in published research and therefore needs further investigation. Most of the students seem to have misunderstood this concept, deemed so fundamental to be chosen as the 1st ocean literacy principle. This topic is actually missing or superficially stated in elementary school curricula and textbooks of the countries under study, while geography curricula still insist to focus on different ocean basins and their names, thus hindering the connectedness of the one and only vast ocean. In the literature so far, students' perception of ocean basins was marginally investigated only by Brody (1996), within a research concerning knowledge of Oregon's marine resources in a sample of 4th, 8th, and 11th grade students who viewed nearby ocean as a sort of "bowl" with rocky/sandy bottom. In 2007, a list of 110 Ocean misconceptions quoted "The ocean is basically a bowl, deepest in the middle" and "The three big oceans are not connected; each acts alone"; unfortunately, this datum has a limited value because, according to the author, the list was compiled upon anecdotal basis (Feller, 2007). On the contrary, an international study among a large number of older (>16 years old) students revealed that this concept was quite easy for them to correctly answer (Fauville et al., 2018).

Another difficult question for the students of this study was the one on the knowledge of the global water cycle. Most respondents believed that the origin of rainwater was from their proximal sea, instead of the remote warmer tropical ocean. Even if these students are probably familiar with the water cycle in all three countries from early elementary grades, apparently they do not perceive its global dimension. Gaps in understanding the basic processes, connections, and magnitude involved in the water cycle, have been evidenced in previous research among school students (e.g., Ben-zvi-Assarf and Orion, 2005), university students (e.g., Cardak, 2009) as well as pre-service teachers (e.g., Mogias et al., 2015). Children's misconceptions about the water cycle were also reviewed by Brody (1993) and listed by Henriques (2000) within literature-referenced weather misconceptions. Results about students' knowledge of the connectedness of all seas and of the global water cycle seem to highlight a common element: *"environment" as referred to, is essentially conceived as a space surrounding pupils' life rather than a global milieu* (Squarcina and Pecorelli, 2017).

Although the proximity of the Italian students' residence to the sea seems to have affected their knowledge level, this was not the case for the Greeks, where in some cases "inland" students appeared to be more knowledgeable regarding marine issues than "coastal" ones. Relevant literature reveals that, when people experience coastal environments in their childhood and come closer to certain coastal and ocean problems, they are more likely to practice certain skills important for scientific inquiry, obtain relative content knowledge, and therefore develop an interest in nature and later work for its protection (e.g., Chawla, 1999; Cicin-Sain and Knecht, 2000; Steel et al., 2005; Bennett and Hiebert, 2010).

Additionally, in one of the Greek sub-samples, students who live near or have easy access to non-formal educational settings such as an aquarium and a marine research institute, appeared to possess significantly higher level of marine content knowledge, probably indicating the contribution of such educational environments, as well as the self-confidence and enthusiasm of the teachers who take advantage of these settings. It has been revealed that visits to aquaria and zoos have a measurable impact both on knowledge and attitudes (Falk and Adelman, 2003; Falk et al., 2007). As Ballantyne (2004) argues, such non-formal settings are well placed to address misconceptions by designing exhibits, which accurately demonstrate various phenomena and help children distinguish between them.

Furthermore, students' participation in any kind of nature-related activities within their schools revealed higher knowledge scores in the three countries under study, in comparison to their counterparts with no such experience. The need for ocean literacy activities in the classroom has been pointed out from the very first beginning of the Ocean Literacy Framework launching in the early 2000s (e.g., Schoedinger et al., 2006), while in-school environmental activities promoting inquiry-based and authentic problem-solving learning have shown to increase various aspects of students, such as knowledge among others (e.g., Erdoğan et al., 2009).

Finally, gender differences in marine content knowledge seem to have emerged to some extent from the present study, since in both Italian and Greek sub-samples male students tend to be more knowledgeable than their female classmates, while this was not the case for Croatia. This is not an unexpected finding as a tendency seems to be ascertained with males prevailing in content marine knowledge (e.g., Guest et al., 2015) or general environmental or science knowledge (e.g., Meinhold and Malkus, 2005; Martin et al., 2016); relevant literature also supports opposite results (e.g., McCright, 2010).

Although the present study cannot represent the whole student population of the respective countries and therefore cannot allow for unconditioned generalizations, results have potential implications in different directions within formal education, namely curriculum designers, textbooks authors, in-service teachers, and pre-service training programs. More specifically, having in mind of what Strang (2008) suggests, that we cannot be science literate without being ocean literate, there are implications with regard to the curriculum designers and textbook authors, who are most probably unaware and should be essentially informed of the existence of the Ocean Literacy Framework for the needs of future education reforms on a national level. Accordingly, for in-service teachers who probably miss ocean sciences subject matter knowledge, they should be offered training seminars, especially in subject matters not widely encompassed into the school practice, as the ocean sciences issues, offered by professionals, such as marine scientists and marine educators. Finally, regarding teacher training programs, these should incorporate more intensive opportunities for the prospective teachers to acquire environmental knowledge in general and marine knowledge in particular, aligned with the lately introduced Education 2030 Agenda (UNESCO, 2017).

As elementary school students still maintain their natural curiosity about the world that surrounds them, early capturing their attention by adding ocean literacy-related topics in national curricula, and continually nurturing their inherent curiosity in higher education levels, is fundamental (U. S. Commission On Ocean Policy, 2004). Only ocean-literate future citizens will be able to understand ocean-related issues and will have the ability to take responsible decisions; after all, they will be the ones that will fully comprehend that the vitality of the ocean is inextricably connected to their own survival.

AUTHOR CONTRIBUTIONS

AM designed the research project, administrated the instrument, analyzed the data, and wrote the manuscript. TB, GR, MP, MM, PK, and MC designed the research project, administrated the instrument, and wrote the manuscript.

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CLINICAL CASE STUDY
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Building a New Ocean Literacy Approach Based on a Simulated Dive in a Submarine: A Multisensory Workshop to Bring the Deep Sea Closer to People

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The deep sea is considered the largest environment on Earth, providing multiple ecosystem services to human societies. Although its relevance has long been recognized, not enough attention and interest is generally given to it by society, and its study is almost non-existent in formal and informal education. Getting the deep sea closer to the general public would considerably benefit from the commitment of scientists involved in deep-sea research, who could generate effective educational tools based on their own personal experiences in research projects. Here we report the development of an immersive workshop that displays video footage and sounds recorded during scientific dives inside a replica of a submarine. The workshop recreates with as much detail as possible the experience of researchers when exploring the deep sea using modern technologies, in this case a manned submersible. The workshop is conducted by scientists from the same research team which carried out the study, aiming to transmit their expertise and personal experience to participants. The workshop is complemented with additional spaces that allow the exchange of knowledge and ideas between scientists and the general public. It also shows other, more intrusive, sampling methodologies traditionally used to prospect and study the deep sea, putting them in contrast with modern techniques, more respectful with the environment. Since its first exhibition in 2010, the workshop has been displayed at over 50 events held in different locations around Spain, including educational fairs, museums, schools and fishermen associations. Over 6,000 participants have taken part in the activity, most of which have expressed their opinions and suggestions about the workshop by voluntarily filling a specific survey, and thus helping to improve it. They also stated which aspects of the deep-sea life were unknown to them. Thanks to its versatility and to its simple operation, this educational workshop opens a wide range of possibilities to significantly improve the current knowledge on marine life (and deep-sea ecosystems in particular) by the general public, also aiming to reduce the distance between academia and citizenship.

Keywords: submarine dive, ocean literacy, deep sea, marine ecosystems, environmental education

INTRODUCTION

The deep-sea habitats of the world's Ocean, understood as those areas below 200 meters depth, cover more than half of the submerged surface of the planet (Thistle, 2003). Despite their vast extension and limited accessibility, recent multidisciplinary explorations are starting to unveil most of its unknown features. Contrary to previously thought, the exploration of the deep sea has revealed areas with high species richness, which thrive in a world of darkness (Ramirez-Llodra et al., 2010). Deep-sea environments not only host diverse ecosystems, they also play a significant role in the pumping and fixing of atmospheric CO_2, the recycling of major nutrients and the provision of resources to society (Armstrong et al., 2010). There is a need to spread the knowledge about deep-sea environments and its ecosystem services in order to get their value recognized by society, and consequently accounted for (Jobstvogt et al., 2014). A large number of anthropogenic activities are known to seriously threaten their long-term sustainability, including industrial fishing, oil and gas drilling, deep-sea mining, land-based pollution and climate change (Smith et al., 2008; Levin and Le Bris, 2015; Clark et al., 2016). Although impacts on these environments have been documented for long time, governance of the deep ocean is still fragmented, with national and international jurisdictions generally lacking a common framework and mostly focusing on regulating single threats (Mengerink et al., 2014).

The implementation of ecosystem-based management policies in order to hamper the effects of human activities on deep-sea ecosystems would largely benefit from educated societies that consider marine conservation a priority issue (Feinsinger, 1987). The relatively limited education which currently exists about marine ecosystems should become a major concern for the scientific community, and efforts should be placed in developing tools to get people interested in marine-related issues (Gough, 2017). Furthermore, such tools should be developed following the approach adopted by the Ocean Literacy Network (2013). At present, and despite the numerous efforts made in the last few years in engaging people with marine environments, educational tools involving deep-sea habitats are still scarce and usually focused on the advances of underwater imaging technology (Harmon and Gleason, 2009; Kelly, 2014).

As part of the LIFE+ INDEMARES project, the Benthic Suspension Feeders Research Group at the Institute of Marine Sciences of Barcelona (ICM-CSIC) carried out a series of multidisciplinary surveys in the marine area of Cap de Creus (NE Spain), which includes a submarine canyon and its adjacent continental shelf. The underwater images recorded revealed some biologically varied and well-preserved benthic communities, including diverse cold-water coral communities (Dominguez-Carrió, 2018). The great diversity of species and habitats led the Spanish Government to include in 2014 this marine area in the Natura 2000 Network as a Site of Community Interest (BOE, 2014). Given the interdisciplinarity of the surveys carried out and the invaluable opportunity of using a manned submersible for deep-sea exploration, the research team committed to develop an attractive and effective tool to bring the results of the research closer to society, beyond the expected scientific and political audience. The idea took shape in the form of an interactive workshop, which creates an atmosphere similar to that found by researchers when carrying out oceanographic surveys with a manned submarine. The workshop includes real images recorded during deep-sea dives with authentic sounds of the conversations between the pilot and the scientists. The use of specifically designed audio-visuals has already been proven as an efficient tool for education, and it can have a very high impact on learning procedures (Connolly, 2014), including the achievement of Ocean Literacy goals (Fauville, 2017a).

The objective of the workshop is 4-fold. First, it aims to show to the general public the characteristics of deep-sea areas that can be found close to their homes through an ocean literacy-based learning. Second, it aims to encourage participants to understand the importance of carefully observing their surroundings. Nowadays, humans are constantly experiencing an excess of visual stimuli and data, coming from different unstructured and under-defined sources; these processes have even modulated human condition, embedded in which has been defined by Bauman (2000) as "liquid modernity" (Bauman, 2000). Developing sharp observation skills is not only important for research professionals, but also essential to become aware citizens, a highly-valued quality in our current societies (Hogstel, 1987). Third, it aims to narrow the existing gap between the scientific community and the general public in order to engage people in Science, even from an early age. And finally, since the workshop is also conducted by female scientists, it shows that women also lead cutting-edge scientific research, aiming to provide a positive role-model effect on young female students (Bettinger and Long, 2005).

THE WORKSHOP

The workshop entitled "Ocean exploration | Dive in a submarine: There is also life in the darkness" is mainly composed of a wooden replica of a submarine and a set of accessories to facilitate the understanding of the activity. The wooden replica is based on the submarine JAGO from GEOMAR (**Figure 1a**), which has performed over 1,400 dives around the world Ocean. The replica has capacity for 12–15 people seated on the floor, although a little bench can be provided if requested (e.g., for pregnant women or elders). The submarine replica has an entrance in its rear side (**Figure 1b**), consisting of a double door (1,46 and 1,05 m high) to facilitate the access to participants of all ages. A metallic ramp can also be provided in order to facilitate the entrance to people with limited mobility. Both rear doors can be locked and unlocked from inside the replica, allowing an easy and fast exit if required. The replica can be easily moved around with its 4 wheels, which can be blocked during the development of the workshop. The inner walls of the replica are decorated with real images of the control panels of the submarine JAGO to provide a more realistic feeling when inside.

The virtual dive displayed on the TV screen placed inside the submarine replica is based on video images obtained from real dives performed in Cap de Creus area during the INDEMARES

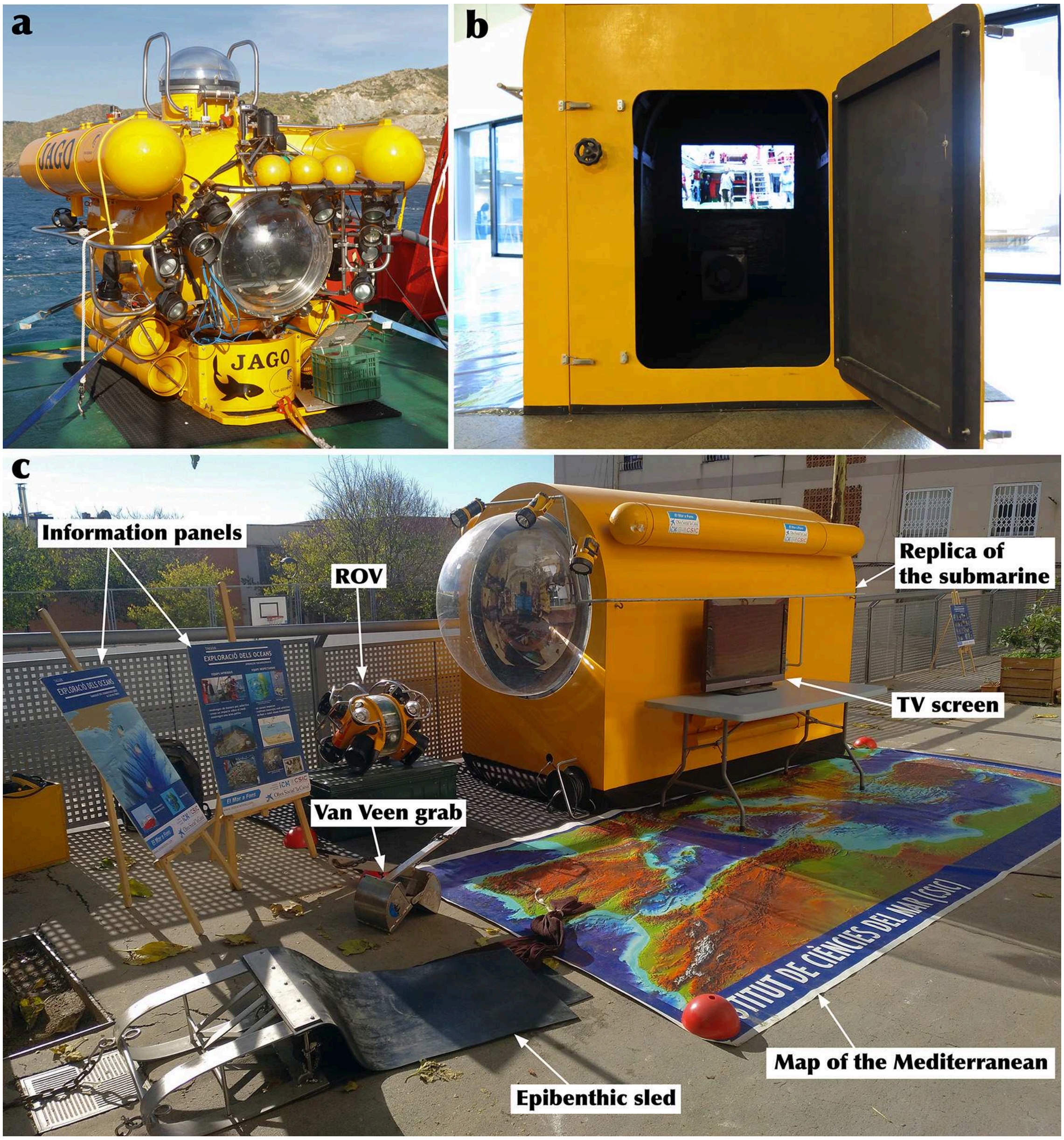

FIGURE 1 | Inspiration and composition of the workshop "Ocean exploration | Dive in a submarine: There is also life in the darkness": **(a)** Image of the manned submersible JAGO (GEOMAR) on board of the R/V Garcia del Cid during one of the INDEMARES surveys in Cap de Creus. **(b)** Rear view of wooden replica of the submarine, with the smaller door opened showing the screen inside. **(c)** Aspect of the replica and the layout of the remaining components of the workshop.

surveys (Project LIFE 07 NAT/E/000732). To provide a more realistic feel, these images are always accompanied by real sounds of the submarine, together with conversations between the pilot and a researcher. The length of the video is 12 min, simulating a dive that explores both the continental shelf and the submarine canyon, reaching depths of up to 400 m (**Figure 2**). The participants are asked to enter the submarine with the video already being played, showing images of the deck and the crew of the research vessel preparing themselves for the deployment (**Figure 3a**). Once the door is closed, the images show how the submarine is being lifted and placed inside the water, always with the perspective of the researcher inside. A depth gauge is displayed on screen at all times as a reference to the participants of the actual depth during the dive. The descent and ascent through the water column is also displayed in order to provide an idea of the great diversity of species that live suspended in the water column (**Figure 3b**) and the large quantity of marine snow that continuously sinks from the surface to the seafloor. Throughout the dive, participants are shown images of different benthic habitats that can currently be

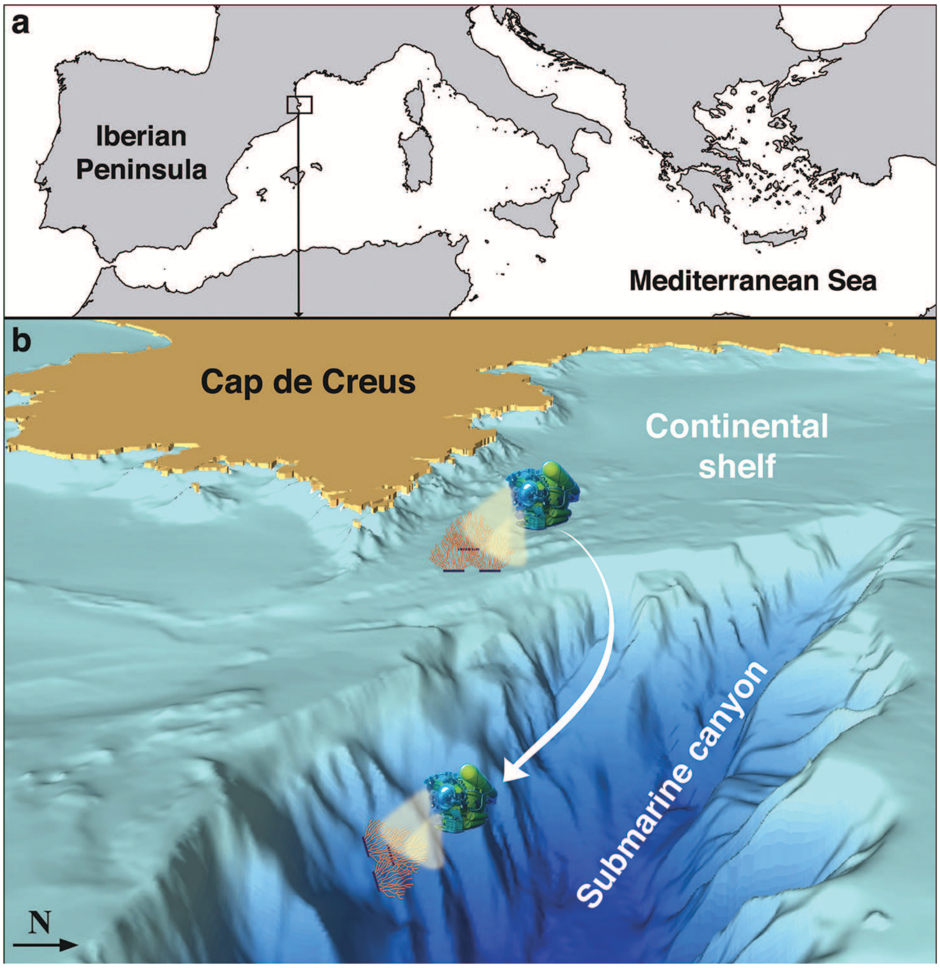

FIGURE 2 | (a) Location of Cap de Creus marine area, at the end of the Gulf of Lions in NW Mediterranean. **(b)** Recreation of the path performed by the manned submersible in Cap de Creus during the virtual dive, starting on the continental shelf and moving towards 400 m depth by the southern flank of the submarine canyon.

found in Cap de Creus marine area: coral gardens dominated by *Eunicella cavolini* (Koch, 1887), fields of pennatulaceans and soft corals, large sponges, a massive aggregation of brittle stars and bioconstructions of the scleractinian coral *Madrepora oculata* Linnaeus, 1758, one of the most emblematic cold-water coral species of the Mediterranean Sea (**Figure 3c**). Close-up images of some coral and fish species are also displayed to focus the attention on some important processes, such as the capture of small crustaceans by the tentacles of the polyps of the corals. The zoom-in effect highlights the importance of paying attention to detail when exploring the deep sea (**Figure 3d**). The negative effects of human activities are also shown during the dive, with images displaying 3 types of impacts: marine litter, an area swiped by bottom trawling and the remains of lost fishing gear (specifically, a trammel net ghost fishing is shown in the images; **Figure 3e**). Towards the end of the dive, the submarine stops to collect a sponge for which the researcher has no reference, with the idea of further analyzing it in the laboratory (**Figure 3f**). The dive ends with the submarine being recovered by the crew of the vessel and placed again on deck. The full video of this activity is provided as **Supplementary Video 1**. Since the workshop began, other versions of the video have been produced in order to show other marine habitats, such as those found in Antarctica.

The external space around the wooden replica is filled with accessories to make the activity more understandable to the public (**Figure 1c**). A large floor map of the Mediterranean region (5 × 2 m long) is placed in front of the replica, illustrating in detail the bathymetry of the Mediterranean Sea, aiming to show its topographic complexity and the large extension of its deep-sea habitats. A second TV screen continuously displaying images recorded during the surveys in Cap de Creus is placed outside the submarine. These images seek to help the attendants get a better idea of the context of the dive, and thus contain footage of Cap de Creus, the R/V García del Cid and the deployment and recovery of the submarine. Three information panels (1.20 × 0.80 m long) are also placed near the submarine, with information about the study area and the trajectory followed by the submarine when underwater (**Supplementary Figure 1**), methods to sample deep-sea habitats, including intrusive and non-intrusive techniques for the study of benthic communities (**Supplementary Figure 2**)

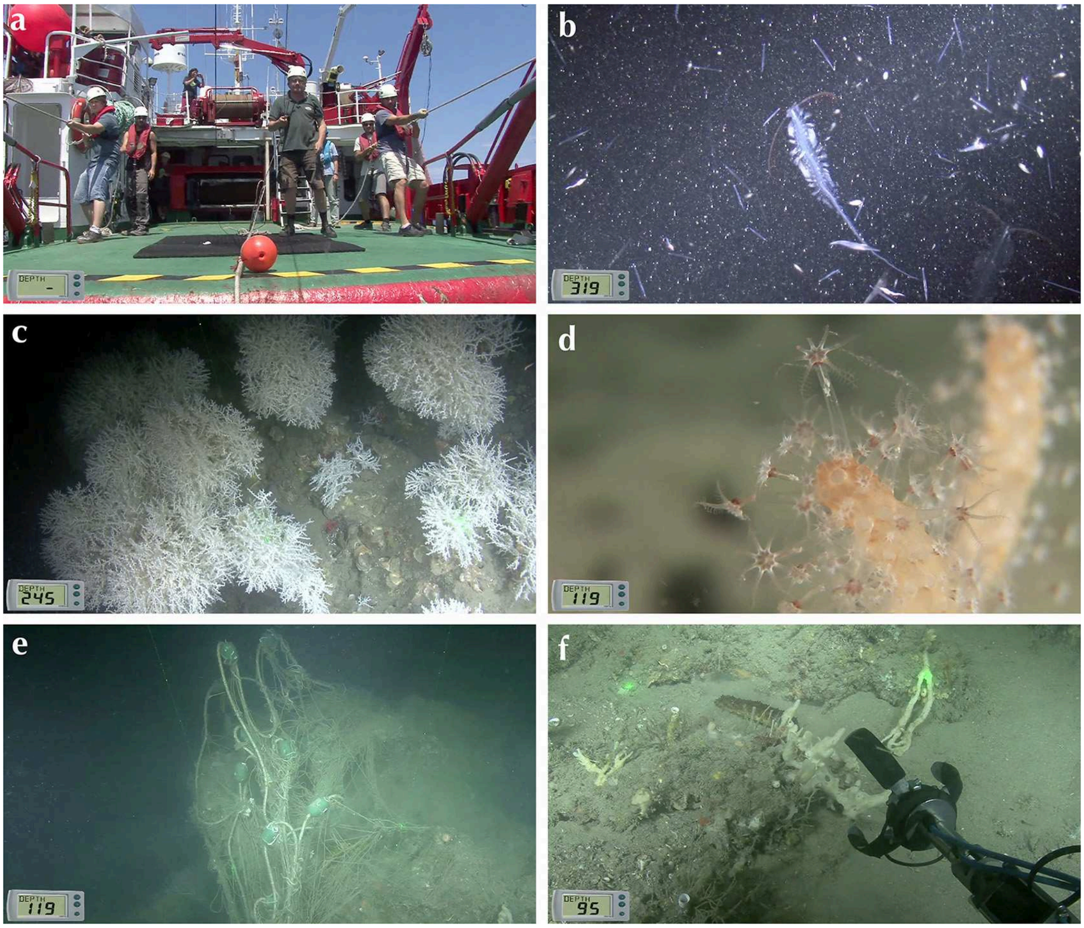

FIGURE 3 | Snapshots showing different moments of the virtual dive: **(a)** The deck of the R/V Garcia del Cid and its crew preparing themselves for the deployment. **(b)** At the deepest point, different plankton lifeforms can be observed in the water column. **(c)** Large colonies of the cold-water coral *Madrepora oculat*a beyond 200 m depth. **(d)** A close-up image showing the polyps of the soft coral *Alcyonium palmatum* fully extended. **(e)** An abandoned trammel net caught on a rock on the continental shelf. **(f)** The moment when the submarine stops to collect a reptant sponge using the robotic arm installed on the submarine.

and a post-video activity to challenge the observational skills of the participants, including images of animals which have and have not been shown in the video footage are also displayed (**Supplementary Figure 3**).

Finally, a set of traditional and modern sampling gears are distributed around the submarine replica to show the participants different methods that can be used to sample deep-sea ecosystems (**Figure 1c**): a small Van Veen grab (used to collect infauna), an epibenthic sled (used to collect epifauna organisms) and a small remotely operated vehicle (used to obtain images of the seafloor).

ASSESSMENT OF THE WORKSHOP

The workshop has been held in over 50 occasions in different locations around Spain, including public engagement events, educational events, museums, schools and fishermen associations. Throughout 8 years, over 6,000 participants have taken part in the workshop, providing an idea of the interest that this activity generates among the public. To gather information about how the workshop is perceived by the participants, a specific survey was provided upon completion of the workshop. The questionnaire consisted of nine closed-ended survey questions based on an agreement scale of 5 levels (1 minimum, 5 maximum) and 15 Yes/No questions about different aspects of the deep sea, covering several Ocean Literacy principles. A model of this survey is provided in the **Supplementary Material**. Until now, 345 filled-in surveys have been collected, for which data has been processed.

The nine closed-ended survey questions were split among three different age groups: children (participants under 12), teenagers (aged 12–17) and adults (above 18 years of age). Surveys including unanswered questions, as well as incongruent answers, were not considered. The most valued element of the workshop, both for children (4.5/5) and adults (4.69/5), was the explanation provided by the scientists prior or just after the dive (**Figure 4**). The idea that marine science topics are better understood when accompanied by scientists coincides with previous studies which have evaluated such interactions (Fauville,

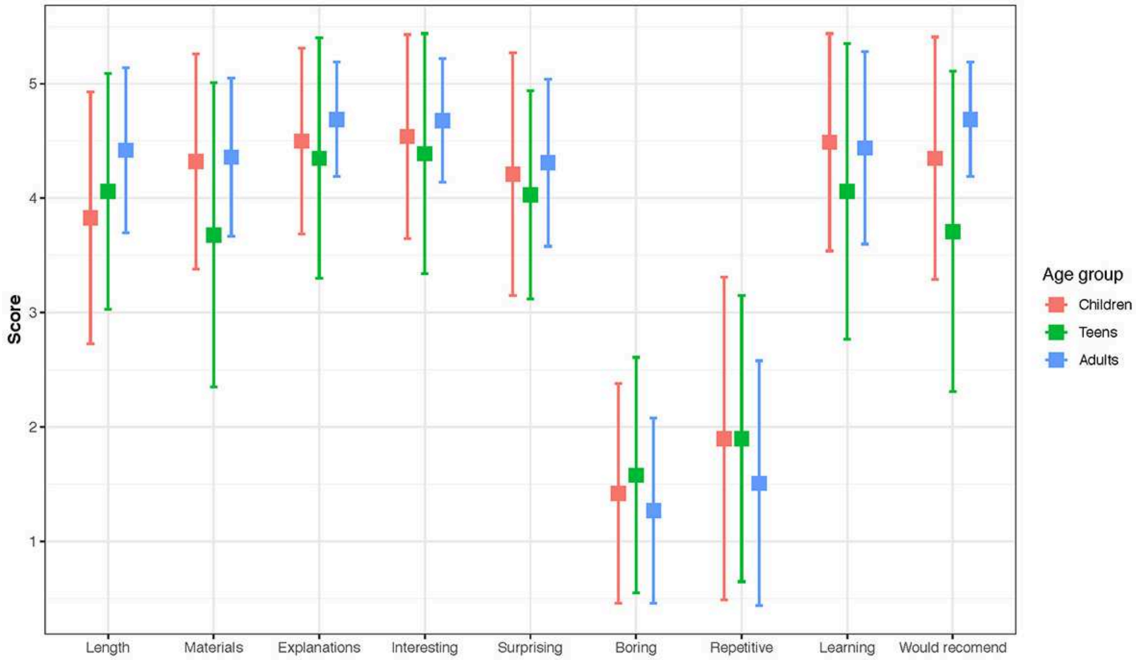

FIGURE 4 | Results (avg. ± s.d.) of the nine closed-ended survey questions among the three different age groups: under 12 years of age, (n = 219), teenagers aged 12–17 (n = 33) and adults (n = 67).

2017b). In fact, the high amount of people that recognized the value of learning highlights the willingness of people to learn about the marine environment when provided with a suitable context (see Lück, 2003 for a terrestrial example). The questions "Is it interesting?" and "Have you learnt something new?" were also positively answered by the three age groups, and adults were the group that would most recommend the activity to friends and family (4.69/5). Finally, children rated the overall length of the workshop the worse (3.82/5), asking for the workshop to last longer on the following answers. Despite this result, a longer-lasting activity would limit the amount of participants that can access the workshop during limited-time events. Due to the difficulties children have in understanding conditional questions, the Y/N questionnaire was only considered for adults. The least known oceanic feature was the existence of marine snow, understood as those particles that sink from surface waters to the deep sea (84% of the participants were not aware of it), followed by 76% of people who did not know that corals and jellyfish were closely related. Interestingly, a staggering 97% of the public knew about the existence of lost fishing nets and abandoned lines over the seabed and 93% knew the existence of bottom trawling as a type of fishing practice. Full results of the survey are provided in **Supplementary Table 1**. We consider that an improved version of the study should be carried out in order to identify knowledge gaps on the understanding of deep-sea processes, which would help in developing specific actions to transmit clear and unbiased information and reverse such trends in the future.

When given the option of an open-answer about the most valued aspect of the workshop, large differences were observed among age groups. A 33,69% of the total answers related to the overall experience of the activity, with adults providing most of their comments in such direction (53%). Examples of these answers included "everything" and "everything was very interesting." Teenagers highly valued the level of expertise shown by the scientists who explained the activity (42%), giving answers like "the way it was explained," "the explanation from … (name of the scientist)" and kids remarked the look and their interaction with the replica of the submarine (43%). Regarding the suggestions provided on how to improve the activity, most participants seemed very content and said that nothing should be added to the workshop (47% for adults, 59% for teenagers and 46% for children, with some enthusiastic answers congratulating the scientists). From those that suggested improvements, some adults claimed that more information could be added (9%) and that the activity could last a little longer (9%). Some teenagers demanded more interactive activities (12%) and some children suggested the display of samples and living organisms (13%) and virtual reality effects (5%), with a relatively high number of answers demanding the presence of more workshops like this one in fairs and schools. Some incongruent answers provided by children and teens also indicate that young students would better benefit from the workshop if the experience was previously prepared with their teachers during classes and discussed thereafter. In this regard, the feedback provided by teachers after installing the replica during a whole week in different schools suggests that these workshops are very successful in bringing Ocean Literacy to the classroom and could provide a significant learning experience for young students (see also Savignon, 2018).

The fact that a high number of children suggested the inclusion of samples and/or living animals as part of the workshop (no adults opted for this option) could indicate that a more respectful way of thinking toward live animals has gained popularity, and it could be expected that children will change their mentality while growing up. Nevertheless, aspects regarding the conservation of life forms in their natural habitat should be worked in depth, especially in formal education (Copejans et al., 2012). Spending time with children in natural marine environments or making them interact with scientists would highly improve their motivation toward the conservation of the marine environment (Winn et al., 2006). Finally, scientists that have conducted the last part of the activity detected a general lack of attention among participants, especially after putting their observational skills to test asking them to point out in a poster what organisms they remember seeing during the dive; **Supplementary Figure 3**).

CONCLUSIONS

Due to its flexibility and simple operation, the educational workshop "Ocean exploration | Dive in a submarine: There is also life in the darkness" opens a wide range of possibilities to improve the knowledge about the deep sea by the general public. It provides a response to the demands claimed by different sectors to develop efficient educational tools as part of the solutions to preserve our Ocean. Some aspects of the workshop could be further explored, as for example providing a choice of locations from a list of predefined simulated dives. It would also be interesting to include more complementary activities oriented to the target audience and more accessory equipment, such as artisanal fishing gears or a box corer. To get a better understanding of how this educational activity reaches the general public, some items of the survey could be better assessed. For instance, the questionnaire about the deep sea could be provided before and after the workshop, to assess how information is incorporated, especially that related to human impacts on marine habitats (industrial fishing, oil&gas exploration, deep-sea mining and climate change). Nevertheless, results indicate that the educational workshop is efficient in transmitting knowledge about the deep sea and the need for conservation, while providing a genuine space for exchanging ideas between scientists and non-scientists. In this regard, and given that the explanations of the scientists appeared as one of the most valued aspects, it seems highly advisable that workshops like this should always be conducted by researchers developing their work in marine related fields, with female scientists acting as role-model for young girls.

ETHICS STATEMENT

The authors consider that an ethical review process is not required for this study because all the compiled data was obtained from surveys filled voluntarily and anonymously. Participants were aware that their answers could be very useful to our teamwork in order to make improvements in the workshop, to value its different aspects and also that we could use the data in our research and publications. The processing of the data follows the Organic Law 1571999 of 13 December on the Protection of Personal Data. All figures and imagery of the workshop was obtained and developed by members of our research group, Benthic Suspension Feeders from the Institute of Marine Sciences (ICM-CSIC), who were committed to develop the educational tool for universal use for El mar a Fons project, under a Creative Commons license. The crew of the R/V García del Cid as well as the JAGO Team (GEOMAR) was committed to help with the development of the workshop and they provided their verbal consent to appear on it if needed. This situation occurs in the video displayed in the wooden replica, when deploying the submarine into the water, when some members of the crew can be identified. They were aware of the possible use of the materials for outreach and investigation purposes.

AUTHOR CONTRIBUTIONS

J-MG conceived the workshop. J-MG, CD-C, and SA designed the workshop and developed its initial contents. All authors have participated during the execution of many workshops and have significantly contributed towards adding content and its improvement. BV-S designed the survey methodology. J-MG, SA, JS, and JG compiled all the data from the surveys and JS, CD-C, and BV-S evaluated it. JS, CD-C, and BV-S wrote the manuscript. All authors critically revised and approved the final version of the article.

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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.2019.00576/full#supplementary-material

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frontiers in Marine Science

BRIEF RESEARCH REPORT
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The Marine CoLAB: Taking a CoLABorative, Values Based Approach to Connect People to the Ocean

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With growing complex and systemic challenges facing the ocean, there is an urgent need to increase the scale and effectiveness of approaches to marine conservation, including protecting and recognizing the value of all of its services. Stronger multi-sector networks of organizations are needed, sharing knowledge and working in unison to create a common narrative for the ocean and the solutions to its protection. In an innovative experiment, the Marine CoLABoration (CoLAB) brings together nine non-governmental organizations (NGOs) to explore collaboratively how to communicate more effectively. The CoLAB hypothesizes that communicating the full value of the ocean in all its rich diversity connects with people's deeply held, personal values and leads to more impactful ocean conservation. Through horizon scanning with the wider sector, the CoLAB determines experiment themes to test this hypothesis. These are based predominantly in the United Kingdom and include #OneLess, Agents of Change and We are Ocean. The CoLAB's work demonstrates that by effectively building and promoting an understanding of the full value of the ocean, it is possible to trigger a wider range of human values to catalyze engagement with marine conservation issues. A joined up, interdisciplinary approach to communicating why the ocean matters, engaging a wide range of actors will be crucial in effecting long term, systemic change for the ocean. The need for greater United Kingdom ocean literacy has also been highlighted across the CoLAB and its experiments and presents an opportunity for further work.

Keywords: marine conservation, values based approach, collaboration, systems change, ocean literacy

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INTRODUCTION

The global ocean provides much of what makes life possible – it produces approximately half of the oxygen on the planet; is pivotal to climate regulation; feeds billions; provides a multitude of livelihoods; and provides many less tangible benefits to human wellbeing (Völker and Kistemann, 2011; Béné et al., 2015; Gattuso et al., 2015). Despite growing knowledge about the importance of the ocean, its health and ability to provide these services is being threatened (Halpern et al., 2017). The ocean is warming and becoming more acidic, sea-levels are rising, oxygen levels are decreasing, all of which threatens marine life already stressed by pervasive pollution, habitat loss and over-exploitation (Hoegh-Guldberg et al., 2007; Domingues et al., 2008; Falkowski et al., 2011; Church et al., 2013; Trathan et al., 2015; Vince and Hardesty, 2017).

The complexity of issues facing the ocean presents a challenge in engaging the public in ocean protection (Steel et al., 2005). Research suggests that there is a significant gap between what scientists and NGOs are saying and public perceptions about ocean conservation issues (Jefferson et al., 2014; Potts et al., 2016; Lindland and Volmert, 2017). Although there has been an increase in public and political awareness around issues such as plastic pollution (Vince and Hardesty, 2018), more work is needed to further global ocean literacy (Cava et al., 2005; Schoedinger et al., 2010; Guest et al., 2015). Research suggests that in order for people to endorse initiatives to safeguard the ocean, interventions need to resonate with people and reflect their values (Gelcich et al., 2014; Esmée Fairbairn Foundation, 2018).

The Marine CoLABoration (CoLAB) was established following research commissioned by the Calouste Gulbenkian Foundation to tackle the lack of collaboration and effective communication around the value of the ocean, identified as a key challenge for the marine NGO sector (Birney and Taplin, 2013). The CoLAB hypothesizes that communicating the full value of the ocean in all its diversity connects with people's deeply held values and leads to more impactful ocean conservation. This article will present three key experiments across the CoLAB that exemplify our approach, together with insights from our model of collaboration.

METHODS

The core group is comprised of nine NGOs: Client Earth; The International Programme for the State of the Ocean; The Institute of European Environmental Policy; Fauna and Flora International; Forum for the Future; New Economics Foundation; Marine Conservation Society; Thames Estuary Partnership and Zoological Society of London. These form a steering group that provide overall governance, maintain the strategy and design the collaborative infrastructure. As part of the CoLAB's approach, the group draws on and conducts values and framing research (Lindland and Volmert, 2017). During its development, the CoLAB developed a collective vision and initiated experiments. It then began incubating experiments which evolved through prototyping cycles, while formulating long-term objectives and operational models. These cross-sector, systemic interventions are identified collaboratively through horizon-scanning and enable the group to investigate real world challenges, addressing key needs around the CoLAB's approach. These include:

#OneLess – A Systems Change Approach to Catalyze a Refill Revolution in London, United Kingdom

#OneLess aims to increase people's connection with the ocean via drawing attention to the ubiquitous single-use plastic water bottle, and, in doing so, foster a more 'ocean-friendly' society and reduce the amount of plastic entering the ocean. In the current system, most Londoners consume water using single-use plastic packaging, which contributes to plastic pollution in the River Thames and the ocean (McGoran et al., 2017). System innovation requires a set of actions that shift a system onto a more sustainable path (Birney and Draper, 2010). Initially #OneLess determined the 'boundary' of the system, identifying challenges and key leverage points. It then established pioneering networks of practice – prototyping and showcasing new and better ways to operate and catalyzing policy innovation. Now it will focus on activities to sustain the transition and set new rules for the mainstream where new modes of water delivery will be taken up more widely.

Agents of Change – Uncovering Shared Value and Developing a New Narrative for Marine Conservation Zones in the United Kingdom

Agents of Change aims to better understand local views about Marine Conservation Zones (MCZs) and use this to support local people in re-framing conversations. The experiment hypothesizes that engaging a wider range of stakeholders in management processes will increase a local sense of connection and ownership of MCZs and lead to more effective and locally accepted management (Bryce et al., 2016; Christie et al., 2017). The experiment brings together a group of national NGOs and sea-users from Sussex and North Norfolk in three pilot areas: Beachy Head East, Kingmere and Cromer Shoal Chalk Beds, building on previous work (Cumming and Norwood, 2012) and testing innovative approaches with communities and MCZs at different stages. Collaborative facilitation techniques including community visioning workshops (Sheppard, 2006) are encouraging local groups to share aspirations for their community and priority steps to achieve aspirations. In Kingmere, the experiment is capturing perceptions of the MCZ through stakeholder interviews, and increasing the visibility of the MCZ through a community-focused website (Agents of Change, 2018b). At Beachy Head East, a recommended MCZ, the experiment is engaging stakeholders through the Backing Beachy Head East campaign (Agents of Change, 2018a).

We Are Ocean – Collaboration to Establish a New Ocean Literacy Network

Since the CoLAB's inception, there has been considerable energy and enthusiasm among environmental and other organizations to build a network to transform levels of ocean literacy in the United Kingdom. This manifested itself initially as a learning community of marine education practitioners, led by the Marine Conservation Society. As the community grew, it developed into the We are Ocean network, comprised of a small core of organizations, aligned by shared objectives on the need for effective ocean literacy collaboration. The group tests new approaches and draws on strengths in existing work, developing interventions that collectively make a bigger impact. The first was World Ocean Day for Schools, launched on World Ocean Day

2018. This experiment aims to catalyze a shift in United Kingdom ocean literacy and inspire students, teachers and parents to learn about and connect with the ocean via a digital schools' package (Wild Labs, 2018).

RESULTS

Independent evaluation using stakeholder interviews and learning exchange workshops across the CoLAB suggest that the group have developed a collaborative ethos, an ecosystem of skills and bilateral exchange of knowledge and insights with over 100 organizations engaged through experiments (**Table 1**). Members are also developing a model of systemic working and a collective knowledge base around the elements of the CoLAB's approach (Baker and Usher, 2018). The CoLAB has found willingness among a diverse range of actors within the marine conservation sector and beyond, to engage in collaborative experiments and campaigns with learning appearing to be particularly high among non-typical ocean actors (Chambers, 2018). For example, #OneLess works to prototype and showcase innovative practice, with the Natural History Museum, ZSL London and Whipsnade Zoos, Selfridges and Borough Market, all eliminating single-use plastic water bottles from their premises and engagement with the Mayor of London resulting in funding for 20 sites for public water fountains across London (Baker and Usher, 2018). Agents of Change has found success in creative socio-cultural engagement as an approach to encourage dialogue with local groups. This has included community visioning workshops, engaging a local crochet network to create a model of the MCZ

TABLE 1 | Examples of the Marine CoLAB's impact, drawn from independent evaluation, including stakeholder interviews, learning exchange workshops and experiment reporting.

CoLAB Principle	Outcome	Learning question	Examples of impact
Communication	The capacity of the sector to communicate the value of the ocean in human well-being is increased so more people understand why a healthy ocean matters and take action to protect it	How is the Marine CoLAB contributing to better communication of the value of the ocean?	• Experiments communicate and frame the value of the ocean in a way that appeals to a range of human values. #OneLess, for example, frames the single use plastic water bottle (SUPWB) problem in London as an ocean issue; project partners have ascribed wider reach to this framing (Chambers, 2018). • Experiments help to kick-start new conversations about the ocean, for example, through World Ocean Day for Schools, engaging education practitioners with the need to protect the ocean (Baker and Usher, 2018).
Capacity building and engagement	The work of others (our organizations, other NGOs and funders) is improved through taking a CoLABoratory and values based approach	How is the Marine CoLAB sharing learning and building capacity in adopting a VBA and CoLABoratory approach?	• Partners are building new skills and knowledge from the CoLAB's approach and take new ways of working back to their organizations and networks (Baker and Usher, 2018). ◦ This has included taking amigurumi ocean creatures to High Seas Treaty Negotiations, designed to switch delegates out of negotiator mode and remind them of the wider value of the ocean and importance of high seas protection (High Seas Alliance, 2019).
Experimentation	Experiments that test a values based approach deliver measurable progress toward ocean health	How is the Marine CoLAB leading to better management and increased protection of our ocean?	• Experiments are inspiring and enabling behavior change. This has included: ◦ More than 1000 people responding to the Backing Beachy Head East campaign. ◦ Selfridges, ZSL Whipsnade and London Zoos all ceasing to sell SUPWBs. ◦ The Mayor of London committing to installing drinking fountains across London with £2.5 million of funding (Baker and Usher, 2018). ▪ 84% of fountain users surveyed through #OneLess agreed or strongly agreed that they consciously avoid using single use plastic bottles because they want to protect the ocean (Nolan et al., 2019).
Collaboration	Collaborations between Marine CoLAB organizations and with those beyond the Marine CoLAB is strengthened	How is the Marine CoLAB strengthening collaboration between Marine CoLAB organizations and those in the wider Marine sector?	• The CoLAB has built exceptionally high levels of trust between members and a commitment to collaborate (DP Evaluation, 2017). ◦ To date, over 100 organizations have worked with the CoLAB, with 59 members engaged through #OneLess (2019). • Experiments are creating a space for people working in the marine sector to consolidate, develop their work and share learning together (Baker and Usher, 2018).

and a collaborative exhibition between local fishers, divers, anglers and photographers to celebrate the local black bream (*Spondyliosoma cantharus)* population (Worthing Borough Council, 2019).

The CoLAB's experiments reveal that participatory processes can foster wider collaboration. The Agents of Change 'Backing Beachy Head East' postcard campaign for example engaged over 1000 members of the public and all three local MPs with the designation process (Baker and Usher, 2018). Community visioning workshops are also revealing priorities locally for MCZs, including a need for increased information flow to visitors and locals, and education of children about their local MCZ (Chambers, 2018). The need for increased ocean literacy is echoed across the experiment's pilot sites, highlighting that communities may be aware of their local MCZs, though do not fully understand its benefit to them (Tebb, 2019). Greater ocean literacy has also emerged as a priority from the CoLAB's horizon scanning activities, and across other experiments, including the World Ocean Day for Schools experiment, with more than 400 schools engaging in 2018 (Baker and Usher, 2018).

DISCUSSION

To enable systemic change and innovation, stronger networks of organizations are needed, working together across sectors and disciplines, sharing knowledge and expertise (Schaffers and Turkama, 2012; Baird et al., 2019). A collaborative approach has been called for that builds interdisciplinary scientific capacity, 'puts the ocean back together' and promotes coherence and innovation in the messaging and actions of the sector (Leslie and McLeod, 2007; Wyborn and Leith, 2018). Investing time in a group and allowing space for reflection and relationship development is crucial in fostering collaboration (Guerrero et al., 2015). Clear onboarding and transparency has also been vital in building an understanding of the CoLAB's approach and ethos (DP Evaluation, 2017). Through creating a joined up vision the CoLAB is able to move quickly, exemplified in an open letter to the United Kingdom government following "Blue Planet II", with 37 organizations signing up to three key actions (Calouste Gulbenkian Foundation, 2019). The CoLAB is looking to build on this learning by scoping the development of a collaborative communications strategy for those that frame the ocean. The group recognizes that working collaboratively to tackle complex and systemic issues can be challenging and requires continual assessment of new approaches, including testing new models in collaborative governance, creative approaches to engagement and learning from success and failure as outlined by other researchers (Brennan, 2018; Clarke and Crane, 2018; Rilov et al., 2019). The CoLAB's experiments have been effective as a method to engage, collaborate and build relationships, helping to embed the group's approach within participating organizations and beyond. Experiments are modeling recommendations from framing research (Lindland and Volmert, 2017) and testing values based approaches to communication. #OneLess, for example, is communicating to values including universalism and protecting the environment as well as self-directive values around pride. These include slogans like "drink water the London way." Partners working across the CoLAB's experiments are also reporting the value of place-based approaches and localism, allowing teams to learn from what is working in one area and scale where appropriate (Chambers, 2018). Research in the field of marine social science, including public perceptions of the marine environment and marine citizenship is fast moving and expanding rapidly (McKinley and Fletcher, 2010; Jefferson et al., 2015). It will be crucial to continue to build the CoLAB's collective knowledge base in this area and engage with research to ensure its evolution.

CONCLUSION

The CoLAB seeks to grow the community to all organizations interested in a collaborative approach to creating a more ocean-friendly society and will refine its support to the community through specific tools. The CoLAB exemplifies the value of building effective, long-lasting and cross-sectoral collaboration beyond existing networks to tackle complex, systemic issues such as ocean health. It requires honesty, transparency and time to build relationships and foster group commitment. In order to make the case for investment in collaboration across the sector, it will be crucial to communicate its often less tangible and long-term value.

As the CoLAB continues to experiment with collaborative governance models, it will trial a new model, which takes a three-pronged approach to: shift the narrative; identify and address strategic gaps; and build capacity and engagement. The CoLAB will continue to grow existing experiments whilst incubating new ones which address strategic challenges. The need for greater United Kingdom ocean literacy is highlighted across the CoLAB's experiments and presents an opportunity for further work. Increasing the reach of the We Are Ocean network and embedding ocean literacy across the CoLAB's approach will be a key priority.

The CoLAB's experiments reveal that through collaboration and communicating why the ocean matters in a way that speaks to and uncovers shared human values, it is possible to achieve greater cut through to audiences. There is growing appetite in the wider sector to learn from the CoLAB's approach and experiments are resonating with funders. Insights from this approach and model of collaboration may advance ongoing research around the relationship between human values and behavior change with potentially substantial impact for ocean protection.

AUTHOR CONTRIBUTIONS

RC, JL, and SW contributed to manuscript conception and design. RC, SR, AB, and CA contributed content that formed the foundations. RC led the review, design, and development in collaboration with JL, NH, and LH.

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Ocean Literacy to Mainstream Ecosystem Services Concept in Formal and Informal Education: The Example of Coastal Ecosystems of Southern Portugal

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The concept of ecosystem services (ES) emerges as strategic to explain the influences that the ocean, and in particular coastal ecosystems, have on us and how we influence them back. Despite being a term coined several decades ago and being already wide-spread in the scientific community and among policy-makers, the ES concept still lacks recognition among citizens and educators. There is therefore a need to mainstream this concept in formal education and through Ocean Literacy resources. Although important developments in OL were done in the United States, particularly through the National Marine Educators Association (NMEA), this concept was only recently introduced in Europe. In Portugal, several informal OL education programs were developed in the last years, yet formal education on OL and, in particular, on ES is still very deficient. To address this limitation, the "Environmental Education Network for Ecosystem Services" (REASE), founded in 2017 in the Algarve region by a consortium of educational, environmental and scientific institutions, aims to increase OL through the dissemination of the perspective of how ES provided by coastal vegetation may contribute to the human well-being. The projects and activities implemented by REASE focus mostly on formal-education of school children and include: (1) capacity building for K-12 teachers, (2) educational programs to support and develop ES projects in schools, including a citizen science project to evaluate blue carbon stocks in the Algarve, (3) the publication of a children's book about the ES provided by the local Ria Formosa coastal lagoon, with a community-based participatory design (illustrations made by schoolchildren) and (4) a diverse array of informal education activities to raise awareness on the importance of coastal ecosystems on human well-being. REASE challenges are being successfully addressed by identifying threats to local coastal ecosystems that people worry about, and highlighting solutions to improve and maintain their health.

Keywords: ocean literacy, behavior change, project-based learning, blue carbon, coastal ecosystems, citizen science, environmental education, participatory action research

INTRODUCTION

The oceans, covering 71% of the Earth's surface, have a profound influence on human well-being, by providing services or benefits such as oxygen, food, pharmaceutical compounds, jobs and climate regulation (Dupont and Fauville, 2017). At the same time, human activities, such as overfishing, coastal development, pollution, and those causing the rising of CO_2 concentrations in the atmosphere, are influencing the ocean by, for example, making it warmer and more acidic with consequences to the marine organisms and ecosystems (Fabry et al., 2008; Hoegh-Guldberg and Bruno, 2010; Cheung et al., 2013). Coastal ecosystems, as part of the global ocean, should be a particular target in the global conservation agenda for being under the impacts of an increasing population density along the planet coasts (Lotze et al., 2006) and for providing highly valuable services both at the local and global scale (Barbier et al., 2011). For instance, coastal vegetated ecosystems such as saltmarshes and seagrasses have experienced large losses and degradation in the last decades due to urban development and pollution of coastal areas (Lotze et al., 2006), putting at risk all the ecosystem services (ES) we benefit from and depend upon (Millennium Ecosystem Assessment [MEA], 2005). The high value of these ecosystems relies on their role, for example, in maintaining local fisheries, thus in food provision (Unsworth et al., 2018), controlling pollution and diseases by filtering nutrients and pathogens out of the water (Lamb et al., 2017) and protecting the coasts from flooding and erosion (Duarte et al., 2013; Ondiviela et al., 2014). In addition, these ecosystems rank amongst the most efficient ecosystems in sequestering and storing CO_2, thus contributing to climate change mitigation (Fourqurean et al., 2012; Duarte et al., 2013). The carbon stored in coastal vegetation sediments, commonly called "coastal blue carbon" (Nellemann and Corcoran, 2009), remain trapped for very long periods of time (centuries to millennia) resulting in carbon stocks larger than in terrestrial vegetation (Fourqurean et al., 2012; Chmura, 2013; Duarte et al., 2013). However, the capacity of the coastal vegetated ecosystems to provide blue carbon storage and other benefits is threatened as a consequence of the human impacts (Waycott et al., 2009; Pendleton et al., 2012). There is an urgent, global need to revert their degradation and to secure benefits now and in the future (Cullen-Unsworth and Unsworth, 2018).

The concept of ES, i.e., the benefits that humans get from nature (Millennium Ecosystem Assessment [MEA], 2005), emerges as strategic to explain the influences that the ocean, and in particular coastal ecosystems, have on us and how we influence them back, which is the essence of the Ocean Literacy (OL, Ocean Literacy Campaign, 2013). Educating people on marine ES, so they get a better understanding of the tight bond between natural habitats and human well-being, constitutes a powerful strategy to advance toward a more ocean-literate society, i.e., a society that "understands the Essential Principles and Fundamental concepts about the ocean," that "is able to make informed and responsible decisions regarding the ocean and its resources," and that "can communicate about the ocean in a meaningful way" (Ocean Literacy Campaign, 2013). Despite being a term coined several decades ago, in the 1980s (Millennium Ecosystem Assessment [MEA], 2005), and being already wide-spread in the scientific community and among policy-makers, the ES concept still lacks popularity among citizens and educators. There is therefore a need to mainstream this concept in formal education and through Ocean Literacy resources.

The "Ocean Literacy Essential Principles and Fundamental Concepts" (Ocean Literacy Campaign, 2013) is a cornerstone document to guide educators on the seven most important concepts that citizens should know about the oceans. Some of these principles indirectly refer to the ES delivered by the ocean and its ecosystems. For instance, principle 3.f. mentions that the ocean has had, and will continue to have, a significant influence on climate change by absorbing, storing, and moving heat, carbon and water, principle 4.c. "The ocean provided and continues to provide water, oxygen, and nutrients, and moderates the climate needed for life to exist on Earth," principle 5, "The ocean supports a great diversity of life and ecosystems," includes a specific mention (5.i.) to coastal ecosystems, in particular estuaries, in providing "important and productive nursery areas for many marine and aquatic species," and in principle 6 "The ocean and humans are inextricably interconnected," there are many references to marine ES such as food, medicines, jobs, navigation and culture (6.a. to 6.c). These ES-related principles are, however, built on a global scale, so tailoring them to local necessities and problems is needed so that they will have a more efficient impact.

Although important developments in OL have been done in United States, particularly through the achievements of the National Marine Educators Association (NMEA), this concept was only recently introduced in Europe. The first Conference on Ocean Literacy in Europe was only held in 2012. Despite the fact that OL is a political priority to the EU, little has been done to improve it, as recognized by the European Marine Science Educators Association [EMSEA], 2013. OL concepts are not present in most European school's curricula (Water World Adventure Learning Approach, 2016), although Portugal was among the first countries to implement informal OL education projects (**Table 1**), in particular through the project "Knowing the Ocean" that aimed to stimulate the citizens' involvement with the ocean based on the North American Ocean Literacy initiative. In fact, due to the Portuguese geographic location and its long maritime tradition, many education programs that included sea-related activities were developed before OL became the hallmark for sea-related environmental education, for example the centers for monitoring and environmental interpretation, CMIA, in northern Portugal[1,2,3]. In terms of OL targeting specifically the Portuguese coastal ecosystems there are two programs running at present (**Table 1**), Ocean Alive[4], focused on the seagrasses of the

[1]www.cmia-viana-castelo.pt/servicos-educativos/atividades-grupos
[2]www.cmia-viladoconde.net/eventoseatividades.php
[3]www.cmia-matosinhos.net/eventoseatividades.php?page=2&ipp=10&t=2
[4]https://www.ocean-alive.org

TABLE 1 | Past and present ocean literacy education projects developed in Portugal.

Name of project	Website	Promotor	Year of implementation	Still running (yes/no)	Target audience
Sea for Society – Mar para a Sociedade.	http://www.cienciaviva.pt/peixes/home	Ciência Viva Agency	2007–2013	No (web page of resources still available)	General public (on line resources)
KIT DO MAR	https://www.dgpm.mm.gov.pt/kit-do-mar	DGPM	2008–2013	No (web page of resources still available)	Formal education (K12)
ADOPTE	Not available	CCMAR – Center of Marine Sciences, University of Algarve	2010	No	Formal education (Elementary school)
Oceanário Shuttle	https://www.oceanario.pt/educacao/vaivem-oceanario/	Oceanário de Lisboa/Fundação Oceano Azul	2011	Yes	General public
O MARE VAI Á ESCOLA	https://ciencias.ulisboa.pt/pt/o-mare-vai-%C3%A0-escola	MARE	2015	Yes	Formal education (K12)
OceanLab	http://www.ciimar.up.pt/oCIIMARnaEscola/OCEANLAB.php	CIIMAR, CMIA Vila do Conde e CMIA Matosinhos	2015	Yes	Formal education (K12)
Oceanaction	http://oceanaction.pt/projeto	CIIMAR	2015	Yes	Formal education (K12)
Chef Fish Challenge	https://decojovem.pt/alimentacao/concurso-chef-fish/	DECO – consumers defense association	2015–2016	No	Formal education (K12)
Sea Change	http://www.seachangeproject.eu/	Ciência Viva Agency	2015–2018	No (web page of resources still available)	General public (on line resources)
EduCO2cean	http://www.educo2cean.org	ASPEA – Portuguese Association of Environmental Education	2016–2018	No	Formal education (from 15 to 17 years old)
Blue School-Escola Azul	https://escolaazul.pt	Ciência Viva Agency	2017	Yes	Formal education (K12)
Do CO2 ao O2	https://abae.pt/do-co2-ao-o2/	ABAE, European Blue Flag Association	2017	No	General public and formal education (K12)
REASE	http://rease.ccmar.ualg.pt/#home	CCMAR – Center of Marine Sciences, University of Algarve	2017	Yes	General public and formal education (K12)
Ocean alive	https://www.ocean-alive.org/	Ocean alive Coop	2017	Yes	General public and formal education (K12)
SERMARE-PRO – Formação para Professores	https://laboratoriomarefoz.wixsite.com/laboratoriomarefoz/nacionais-1	MARE	2017	Yes	Teacher trainning
Programa Geração azul	https://www.oceanoazulfoundation.org/pt-pt/o-que-fazemos/literacia/	Oceanário de Lisboa/Fundação Oceano Azul	2018	Yes	Formal education (from 5 to 9 years old)
Young People's Parliament (2018/19 THEME: Climate Change Save the Oceans	http://www.jovens.parlamento.pt	Portuguese Parliament	2018–2019	No	Formal education (K12)
Knowing the Ocean	http://www.cienciaviva.pt/oceano/home	Ciência Viva Agency	Not available	Yes	Formal education (K12)

Sado estuary and the network REASE[5], which is presented and discussed below.

Even though some informal OL education programs have been developed in Portugal, there is a need for formal education in the classroom arena, tailored to local ecosystems. Based on this principle, the "Environmental Education Network for Ecosystem Services" of the Algarve region (REASE, from its abbreviation in Portuguese) aims at planning and implementing environmental education projects on coastal ecosystem services with a special focus on the formal-education of school children. The network was founded in 2017 and includes institutions in the Algarve region interested in disseminating the perspective of the ES, namely the Center of Marine Sciences (CCMAR) of the University of Algarve, schools and associations of schools, science outreach centers, teachers training centers and non-governmental organizations.

[5]http://rease.ccmar.ualg.pt/#home

OCEAN LITERACY EDUCATION IN PORTUGUESE SCHOOLS

The main target for ocean literacy dissemination is the primary and secondary students (K-12) because school is mandatory for all and not everyone has access to informal educational contexts. However, ocean literacy and environmental education continues to be disregarded in the formal K-12 curricular programs in Portugal as well as in other European and American countries (Fauville et al., 2012), resulting in a citizenry that is not equipped to deal capably with many environmental problems. Teachers and schools need scientific support to understand ocean problems and to take on the challenges of disseminating OL. Thus, contemporary projects involving scientists, school teachers and students are needed to explore ocean problems in innovative ways. The current REASE project and the MARE and OCEANLAB training programs for teachers (**Table 1**) are good examples of this.

The main obstacles to the inclusion of OL in the Portuguese school is the overly fragmented curricular program by many disciplines, the length of the ordinary curricular program that does not encourage extra-curricular activities, the weak tradition of interdisciplinary project development as well as the lack of conditions for collaborative work among teachers (Santiago et al., 2012; OECD, 2018a). This is particularly relevant because ocean problems are complex and require transdisciplinary approaches. In addition, the Portuguese educational system based on national exams to access higher education at Universities exerts a pressure on teachers, students and families, for whom the main objective is to prepare the students for the exams, promoting a general standardization of school education. However, important reforms have been recently introduced, which may provide an opportunity for the inclusion of OL in the standard curriculum. In July 2018, Portugal officially adopted the Legislative Orders no. 55/2018, which obligates Portuguese schools (1st, 5th, 7th and 10th grades) to join the "Project for Autonomy and Curriculum Flexibility" (PACF). PACF provides schools with the necessary conditions to adjust the national curricular program with local contents. Schools may thus integrate innovative methodologies and practices to promote better learning. This project includes the National Education Strategy for Citizenship to introduce citizenship education in the schools. This strategy has created mandatory teaching areas, such as environmental education, sustainability, human rights and health. In addition, it promotes partnerships with NGOs and other institutions. PACF recommends to develop curricula according to the local contexts, associated with active methodologies such as project-based learning methodologies.

This recent legislation represents an opportunity to introduce and explore the theme of coastal ES and OL in the Portuguese school curriculum. Ocean literacy provides a way for students and teachers to work with their communities, and to change behaviors to reduce negative impacts on the ocean and its resources, ensuring that a healthy ocean will be available for future generations. Furthermore, the OECD (Organization for Economic Co-operation and Development) Learning Framework 2030 (OECD, 2018b) acknowledges that the concept of "competency" implies more than just the acquisition of knowledge and skills; it involves the mobilization of knowledge, skills, attitudes and values to meet complex demands (like the concept of ES). One of the recommendations of OECD's Skills Strategy Diagnosis for Portugal is "adjusting decision-making power to meet local needs."

ENVIRONMENTAL EDUCATION NETWORK FOR ECOSYSTEM SERVICES IN SOUTHERN PORTUGAL (REASE): MISSION AND VISION

The eastern coast of Algarve in southern Portugal is dominated by the Ria Formosa lagoon and the Guadiana river estuary with its Castro Marim saltmarshes. These are coastal protected areas recognized for their ecological and socio-economic importance where the preservation of ecosystems cohabits with their long-term, historical economic exploitation. Ria Formosa lagoon is probably the main employer of Algarve, where touristic usufruct shares this territory with artisanal fishing activities, salt extraction and mostly important, bivalve production. This anthropogenic pressure is increasing and diversifying, producing important disturbances in the landscape, habitats and species. These estuarine-lagoon ecosystems are dominated by seagrasses and saltmarshes, which support high biodiversity including iconic, endangered species such as seahorses, the provision of food resources, the purification of the water and the regulation of nutrient biogeochemical cycles, including globally relevant ES of carbon sequestration, ocean acidification mitigation, enable cultural and recreational practices and goods that relate people with the natural system and many dimensions of well-being that result on high touristic demand. This is the background that motivated the recent creation of the REASE network, whose aim is to increase coastal OL through the dissemination of the perspective of the ES provided by coastal vegetation, and in particular, how saltmarshes and seagrasses contribute to the well-being of the local population. The ultimate goal is to increase awareness of ES to promote the preservation and conservation of coastal ecosystems and the public pressure to manage them for sustainability.

The REASE strategy is not only to focus on primary and secondary schools, which are the key institutions with higher potential to deliver scientific knowledge on ES and OL to students through formal education, but also to deliver informal education of the general public by institutions such as environmental education centers, science centers, museums and aquaria. The specific objectives of REASE are (1) to train primary and secondary teachers on coastal ES and OL, (2) to create an incubator of innovative ES and OL projects that may be developed in schools under the PACF and in environmental education institutions, endowed with the scientific, technical (laboratory and field) equipment for the design, implementation and replication throughout schools, and (3) to promote informal activities for all types of public to improve the awareness on ES and OL. **Table 2** summarizes the activities conducted by REASE,

TABLE 2 | Activities conducted by the REASE network to mainstream the concept of ecosystem services (ES) in the western Algarve region (Portugal), including the target public, objective, and results obtained in the first year.

Activity	Target public	Objective	Results
Continuing teacher training (F)	K-12 teachers	Create capacity building in the education community through theoretical and field training on ES.	82 teachers from 20 schools
Incubator of ES projects (F)	K-12 teachers and students	Develop small scientific projects on ES though scientific support and resource provision.	9 field trips with over 200 students; 6 talks/student conference participations reaching over 250 students Total of 15 events reaching over 380 students
"Being a researcher for one day" program (F)	K-12 students	Student immersion in real ES research activities	3 students
Publication of a children booklet on ES (F/IF)	K-12 students	Involve the local schoolchildren community in the creation of OL resources on ES. Create a free resource on the ES provided by local ecosystems.	20 book presentations (4 of them including fieldtrips); 464 students, 950 booklets distributed
Exhibition stands on coastal ES by coastal ecosystems (IF)	General public	General dissemination of ES concepts	2 science centers
Roll ups on ES of Ria Formosa lagoon (F/IF)	General public	General dissemination of ES concepts	1 shopping mall, 2 nautical fairs and 3 schools

Each activity is categorized in formal (F) and informal (IF) education.

which will be developed below. The number of participating teachers was 82 from 20 schools, which represents 3% of the total number of K-12 teachers in municipalities of eastern Algarve (Loulé, Faro, Olhão, Tavira and Vila Real de Santo António).

Continuing Teacher Training

The training of teachers is central in the REASE attempts to increase the knowledge on ES in the region. This is particularly relevant in Portugal as the ES concept is relatively new (the concept was disseminated by the United Nations Millennium Ecosystem Assessments, publishied in 2005) and the Portuguese teacher's population is old, so that at the time they graduated the ES concept was not known. Data from 2015 to 2016 indicate that in 104,386 school primary and secondary teachers in public schools, there were only 383 under the age of 30. In fact, the age of teachers has increased drastically in the last decade revealing a worrisome lack of renovation. In the 1990's the number of teachers above 50 and below 35 years old was similar (aging index about 100), whereas in 2017 the number of teachers above 50 was 33 times higher than the number of teachers below 35 years old (**Figure 1**).

Given the increasing aging of the teaching class, continuing training of K-12 teachers is fundamental, especially in emerging areas such as ES and OL. Continuing teacher training in southwestern Portugal is formally provided by the Teacher Training Centers of "Levante Algarvio" in Vila Real de Santo António, "Ria Formosa" in Faro and "Litoral à Serra" in Loulé, being all of them involved in the foundation of REASE and in its activities. From the start of REASE in November 2017, to November 2018, a total of 7 training actions for teachers (**Figure 2A**) were delivered on coastal ES by researchers from the Center of Marine Sciences of University of Algarve, CCMAR. Eighty-two teachers from 20 schools were trained in the first year, 60 of which have implemented related activities to approximately 1200 K-12 students.

Incubator of ES Projects

The REASE network includes an "incubator of ES projects" (**Figure 2B**) that provides scientific support to K-12 education centers to develop small scientific projects with their students as an opportunity to learn about current scientific research related to ES. The learning process in science is more effective when the students are introduced and directly immersed into the scientific work throughout an "inquiry" learning process, instead of just learning about the "products" of science. They should have a question to investigate as a background of the learning process (Dewey, 1938). The ES projects launched within this framework were therefore based on experimentation, so students follow the scientific process of formulating problems, testing hypotheses, analyzing data, finding answers and presenting and communicating the results. This approach aims to reinforce the principle that an ocean-literate person may be able to communicate about the ocean in a meaningful way, a skill that the students put in practice through participation in various school events (conferences, competitions, meetings) where they present the results of their investigations. Finally, the incubator of ES projects is also based on the principle that field visits and experimentation are unique opportunities to learn about the coastal ecosystems and their services since, during such activities, students interact with the ecosystems through observations of natural processes and learn how they are connected to their well-being.

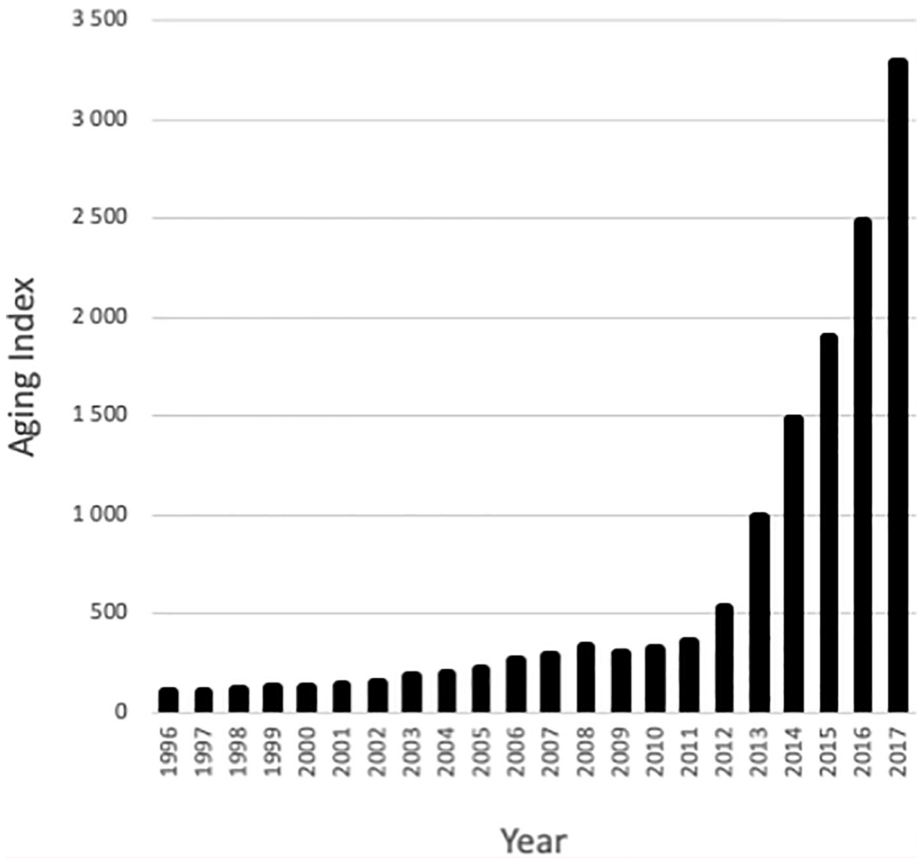

FIGURE 1 | Aging index (no. of teachers with more than 50 years/no. teachers with less than 35 years × 100). Source: Pordata (https://www.pordata.pt/DB/Portugal/Ambiente+de+Consulta/Tabela, assessed in 13-12-2018).

The flag pioneering project of REASE incubator is the "Carbono Azul" (Blue Carbon). This scientific project aims at mapping the blue carbon stocks of coastal vegetated ecosystems in the Algarve region[6]. Mapping the blue carbon stored in saltmarshes and seagrasses requires some training on the scientific protocols to quantify the organic carbon stored in the sediment and vegetation, as well as specific laboratory and field resources that may not be available in every school. For that reason, the first step was the implementation of training actions for teachers (see previous sub-section "training"). Secondly, the schools were provided with a field kit containing the materials needed to collect and analyze vegetation and sediment samples, including among other items, a handheld GPS, sampling cores, thermometer and zip lock bags (**Figure 2B**). In addition, one of the schools of the REASE network (AEJD Faro) was assigned as the "Incubator of ES project" headquarters and it was provided with laboratory equipment needed for the analysis of samples (laboratory oven and muffle furnace), to be shared with all other schools, teachers and students included in the REASE network, reinforcing in this way the inter-school cooperation and sharing of resources. Apart from the laboratory equipment needed for the "Blue Carbon" project, the "Incubator of ES project" headquarters was provided as well with microscopes and binocular magnifiers to develop other scientific projects. The Blue Carbon project is supported by a digital platform where the blue carbon data may be deposited and shared. The Internet and geographic information system (GIS) web applications developed by REASE allow participants to collect large volumes of location-based ecological data and submit them electronically to a centralized database. An *app* is also being developed[7] to directly upload field measurements, photos and blue carbon data into the website of the project, where data are scientifically validated and analyzed by CCMAR researchers. The ubiquity of smartphones, the potential for digital photo and the development of an infrastructure for creating simple online data-entry provide added potential for democratizing the project development, allowing the creation of data-entry systems for community-based projects of ecological research as Dickinson et al. (2012) recommended. Such empowerment means that data that may drive resource management decisions, are more likely to be in the hands of the people who will be affected by the outcomes, which reinforces the degree of participation and implication and guarantees its own sustainability.

[6]http://rease.ccmar.ualg.pt/#map

[7]http://rease.ccmar.ualg.pt/#app

FIGURE 2 | REASE activities for formal education includes **(A)** continuing training for K-12 teachers on ecosystem services (ES); **(B)** an incubator of innovative projects on ES, such as mapping the blue carbon in the Algarve that includes the delivery of a field kit; **(C)** field trips with schoolchildren; **(D)** using storytelling to educate on ES using local examples; **(E)** researcher for one day program; and **(F)** public presentations. All identifiable individuals have delivered a written consent for the publication of the images.

In the framework of the "Incubator of ES projects," the REASE network has co-organized field trips with schools to the Ria Formosa Natural Park and the Castro Marim saltmarsh Natural Reserve in which about 500 K-12 students have participated in the last year (**Figure 2C**). During the field trips, the "Blue Carbon" and other projects (e.g., assessment of the ES of biodiversity support by seagrass meadows, in particular commercial bivalves) have been implemented, in which students actively participated in the collection of plants and sediment samples from different locations and measured environmental parameters.

The "Formosa" Story: A Booklet for Children on ES

The use of appropriate stories may enhance the Ocean Literacy of children and also educate them toward a more sustainable attitude in relation to the environment. When a child listens to a story narrated by a person who has a deep knowledge on environmental issues, it has the chance to experience a new field of sensations by becoming a part of the story (Barton and Booth, 1990). REASE followed this approach by publishing a children booklet entitled ("Formosa")[8] that is being used as an educational tool for teaching the ES provided by seagrass meadows in the Ria Formosa lagoon. The creation of the booklet was, at the same time, an educational and participatory project, in which local schoolchildren prepared drawings to illustrate the booklet after hearing the story from the author at their school and after participating in a field trip to visit the ecosystem that is the booklet's protagonist, the seagrass meadows of Ria Formosa. The published booklet was then presented to the local community in a public event where children, parents and scholars were invited. After its publication, about 20 presentations (**Figures 2D,F**, 4 of

[8] http://rease.ccmar.ualg.pt/downloads/attachments/FORMOSA%20Maquete%20210x148mm_4c.pdf

them including a field trip to visit seagrass meadows, **Figure 2C**) of the booklet story were given by its author to more than 400 children at schools and *Ciência Viva* centers. A total of 950 paper copies were distributed in the first year in schools and in several fairs and other ocean-related meetings and events.

"Researcher for One Day" Program

While knowledge of the theoretical framework of the ES and OL topics is indispensable, it is not always easy to directly relate it with the real world. In most cases, students have very little knowledge of the coastal marine habitats in the Ria Formosa as a real-world concept, despite living extremely close to them and having studied them in the classroom. The only exceptions are the children of the lagoon's users, such as fisherman and clam cultivators. To promote engagement and active education, REASE developed the "Researcher for one day" program where selected students (by their teachers) participated in the research activities of CCMAR, directly interacting with researchers during a field sampling campaign (**Figure 2E**). This allows a hands-on experience, and interaction with someone who has experience on scientific issues related to ES. This direct contact can be critical to instilling a life-long interest in science. Such arrangements are, however, difficult to organize on a large-scale, due to practical limitations.

Informal Education

The formal education is the main focus of the REASE network to mainstream ES in the eastern Algarve region, but learning is not limited to formal education. To embrace a wider audience, different informal activities were developed, including exhibitions, workshops, "talks with scientists," radio interviews to REASE members, among others. The *Ciência Viva* science centers (of Faro and Tavira), as partners of the REASE network, had an active role in the informal education activities through the presentation of a permanent interactive exhibition on the ES of coastal vegetated ecosystems of Ria Formosa lagoon (**Figure 3A**). As well, roll-ups on the ES services of Ria Formosa lagoon (**Figure 3B**), namely the water purification, the carbon sequestration, biodiversity support and ocean acidification mitigation, were prepared and exhibited in shopping malls, nautical fairs and in schools to commemorate environmental events.

CHALLENGES AND LESSONS LEARNED

The greatest challenge of REASE is to raise the awareness of K-12 students on the benefits that coastal vegetated ecosystems deliver and how they are crucial for the well-being of populations. This challenge was addressed first by training and rising the ES awareness of school teachers who then conveyed it to students. This is probably the best strategy to reach most of families and thus a vast audience, through their children (Uzzell et al., 1994; Ballantyne et al., 1998; Bamberg and Möser, 2007). If the youngest of families learn the benefits of local ecosystems, there is a good possibility that this knowledge will pass on to their parents raising their awareness as well. In order to increase successfully the awareness of teachers and then of students, it is fundamental to make it interesting and exciting. This challenge was successfully addressed by identifying threats to local ecosystems that people worry about, and by discussing solutions to improve and maintain their health.

Then it was necessary to implement exciting projects that involved not only laboratory work but most importantly, field excursions and sampling so that the teachers and their students get in touch with the natural environments and may break the monotony of the day to day work within the school buildings. For this, we developed a close collaboration between researchers and educators. A model project was developed, the Blue Carbon Project (see text footnote 6), whose field and laboratory protocols were tested and improved with teachers. A critical component was the creation of educational materials, including information that allows participants to understand the scientific background, a field kit with everything necessary to collect samples and field information, clear and precise field and laboratory protocols and laboratory conditions to analyze the samples. Potential educational benefits of REASE projects range from acquiring skills needed to collect data accurately to critical scientific

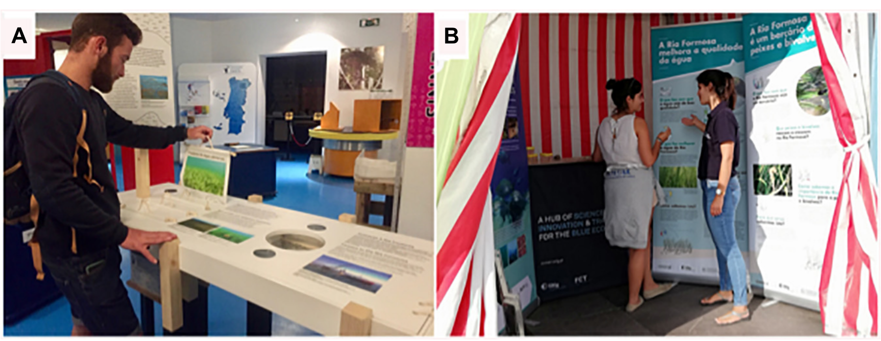

FIGURE 3 | REASE activities for informal education include, among others, **(A)** interactive permanent exhibitions on ES of coastal vegetated ecosystems at science centers, and **(B)** roll-ups exhibitions in shopping malls, nautical fairs and in schools. All identifiable individuals have delivered a written consent for the publication of the images.

thinking and inquiry, in which participants apply knowledge to generate new questions and then design studies or develop models to answer those questions. Furthermore, the data collected is scientific valuable once is validated by researchers, and has in itself educational value. The experience of collecting data for use by professional scientists is highly motivating, fosters scientific knowledge, and provides opportunities for interacting with members of likeminded communities within local environments (Bonney et al., 2014). The deeper involvement of teachers and students in REASE activities is resulting in increasingly robust learning outcomes. It is gratifying to see that the number of schools and teachers interested in participating is steadily increasing and that researchers have been invited for a number of informal events to discuss on local environmental issues and problems.

One of the lessons learned is that teachers need to understand that not knowing the answer is okay and that science does not have answers to all the questions and problems. Teachers need to overcome the paradigm that they are the holders of all knowledge, to a new paradigm where teachers and students have to co-construct knowledge so that the learning process is focused on the student. Additional training and resources to facilitate this paradigm are needed, for example, methodological training directed to cooperative work, problem-, project- and inquiry-based learning. On what concerns resources, the challenge is how to overcome difficulties related to heavy and fragmented curricula by many disciplines giving limited time to develop projects with students, large numbers of students per class, reduced budgets, lack of transportation to take the students to the field, and many other growing challenges facing schools. However, during the REASE first year, teachers have found ways to overcome those challenges and have shared them within the network so that others may benefit from solutions found, for example developing partnerships with the municipalities and the national agency "Ciência Viva"[9]. Our empirical assessment, based on the feedback received from teachers, shows as well that it is possible to develop interdisciplinary projects integrating various subjects such as biology, geology, physics, chemistry, geography and mathematics. This is particularly relevant because ocean problems are complex and require interdisciplinary approaches.

Environmental and educational impacts of REASE are difficult to measure. However, we are considering three distinct ways of evaluation: the contribution to scientific knowledge through the ES data that is being collected and is being made available at the site (see text footnote 6), the number of blog news published on the activities developed with the students[10] and the impacts on behavior, i.e., if participants become more environmentally responsible individually or collectively, in the present, or in the future. Outdoor educational interventions, including field trips and experiential work, have generally a positive effect (Fiennes et al., 2015), but this effect is attenuated over time. This reinforces the need for continued interventions as it is being done in REASE rather than timely interventions. The long-term effects of REASE may be evaluated by mixed method methodologies including quasi experimental research design (e.g., pretest–posttest), semi-structured interviews and focus groups (Cook and Campbell, 1979; Stern et al., 2014). A relevant immediate impact of REASE was the successful submission of the project Erasmus + 2018-1-PT01-KA229-047540, Human Impacts @ Coastal Ecosystems," by one of the schools of the network, "Francisco Fernandes Lopes." The project involves 6 EU countries to recognize the importance of protecting coastal ecosystems and among other objectives includes the implementation of the Blue Carbon project of REASE in those countries.

With increasingly severe local and global environmental problems, time is running out to develop an ocean literate citizenry that is "capable of understanding, supporting, and demanding the policy changes necessary to protect the ocean" (Schoedinger et al., 2006). Ocean-literate individuals take action, and through active participation in OL experiences, attach emotion and values to the ocean and its resources. However, ocean literacy and environmental education continues to be sub-valorized in the K-12 educational system in Portugal, resulting in a citizenry that is not equipped to deal proficiently with many environmental problems that are considered out of sight and out of mind. PAFC reform could be an opportunity to change this. The PAFC project gives legal space for all schools to spontaneously and progressively adhere to the possibilities for curriculum design, especially project-based learning, where the promotion of OL could conquer a *pool* position.

AUTHOR CONTRIBUTIONS

HB, CS, and RS contributed conception and design of the study. All authors wrote sections of the manuscript, contributed to manuscript revision, and read and approved the submitted version.

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[9]http://www.cienciaviva.pt/home/

[10]http://rease.ccmar.ualg.pt/#news

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Ocean Literacy and Knowledge Transfer Synergies in Support of a Sustainable Blue Economy

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Since 2011, when the first European ocean literacy (OL) project was launched in Portugal, the number of initiatives about this topic in Europe has increased notoriously and their scope has largely widened. These initiatives have drawn from the seven "OL Principles" that were developed by the College of Exploration OL Network in 2005. They represent a source of inspiration for the many endeavors that are aiming to achieve a society that fully understands the influence of themselves – as individuals and as a population – on the ocean and the influence of the ocean on them. OL initiatives throughout the past years, globally, have resulted in the production of countless didactic and communication resources that represent a valuable legacy for new activities. The OL research community recognizes the need to build up the scope of OL by reaching the wider Blue Economy actors such as the maritime industrial sector. It is hoped that building OL in this sector will contribute to the long-term sustainable development of maritime activities. The ERASMUS+ project "MATES" aims to address the maritime industries' skills shortages and contribute to a more resilient labor market. MATES' hypothesis is that through building OL in educational, professional and industrial environments, it is possible to build a labor force that matches the skills demand in these sectors and increases their capacity to uptake new knowledge. The MATES partnership will explicitly combine OL and knowledge transfer by applying the "COLUMBUS Knowledge Transfer Methodology" as developed by the H2020-funded COLUMBUS project.

Keywords: blue economy, knowledge management, ocean literacy, skills, stakeholder engagement, knowledge transfer, education

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SUGGESTING THE LINKS BETWEEN OCEAN LITERACY AND KNOWLEDGE TRANSFER

The ocean represents 71% of the Earth's surface and it drives many features of life on Earth. The ocean makes the planet habitable and it hosts a vast majority of the living organisms. It regulates climate and it is a major source of water, nutrients, chemicals and oxygen (Valdés et al., 2017).

Human beings have an extremely complex, interconnected and inseparable relationship with the ocean. The ocean is crucial for man-kinds' wellbeing as it provides a vast quantity and diversity of services, such as health, food, transport, discovery, culture and inspiration. These factors broadly explain the importance of the ocean for humans and inspire the "Ocean Literacy (OL) Principles"

(The Ocean Literacy Network, 2005). However, ocean health is seriously threatened, as it is forced to bear multiple anthropogenic pressures and is exposed to unsustainable practices such as overfishing and pollution. The cumulative effects of these drivers are causing biodiversity loss and habitat destruction; changes in biogeochemical and physical processes (such as ocean acidification); and, global warming, thus, contributing to climate change (Baker et al., 2019). There is a need to broadly acknowledge this situation, understand its consequences and take action at all levels – at land and sea – to achieve a sustainable existence of life on Earth, also manifested in the adoption of the United Nations Sustainable Development Goals, (SDGs) which call for action by all countries to promote prosperity while protecting the environment. In this discussion, SDG14 comes into play, with the particularly relevant Target 14.a. International ocean science cooperation is essential to increase scientific knowledge, develop research capacity and transfer marine technology (United Nations General Assembly, 2015). Ocean science is also critical to inform a range of international legal and policy developments concerning, for example, climate change and the conservation and sustainable use of marine biodiversity in areas within and beyond national jurisdiction; or the achievement of the Good Environmental Status in the EU marine waters by 2020 as proclaimed objective of the Marine Strategy Framework Directive.[1]

Developed over a decade ago, the seven OL Principles represent a source of inspiration for those working toward achieving an ocean literate society; one formed by individuals that fully understand the influence they have on the ocean and the influence the ocean has on them (Cava et al., 2005). The seven OL Principles are:

1. The Earth has one big ocean with many features.
2. The ocean and life in the ocean shape the features of Earth.
3. The ocean is a major influence on weather and climate.
4. The ocean made the Earth habitable.
5. The ocean supports a great diversity of life and ecosystems.
6. The ocean and humans are inextricably interconnected.
7. The ocean is largely unexplored.

The OL movement has developed a framework for the introduction of ocean science in schools' curricula and it has produced countless didactic and communication materials which represent a valuable legacy for future activities (Intergovernmental Oceanographic Commission - Unesco, 2018). It is expected that, as a result of the efforts to promote the inclusion of ocean sciences at all levels in education, younger generations will be the first in developing more sustainable behavioral patterns, and that their actions and convictions will instill a society-wide culture change. As distinctly mentioned in the *OL for All: A Toolkit*, in the future "*OL will embrace all subjects, not only science, but also art, music, archeology, culture, geography, and [it is hoped] that definitions, principles and concepts will be adapted and developed to make it relevant locally*" (Santoro et al., 2017). Therefore, there is potential to expand further the OL legacy beyond the educational sphere. It could reach other facets of citizens' lives such as its adoption in professional careers and industrial activities in different sectors, including those directly connected with the *Blue Economy* (World Bank and United Nations Department of Economic and Social Affairs, 2017; Realdon et al., 2018). In fact, ocean literate marine and maritime stakeholders would be expected to understand and acknowledge that ocean productivity and carrying capacity are finite, and therefore, they would be able to make more realistic projections about the scenarios for Blue Growth (Uyarra and Borja, 2016). The urgency of action needed to restore the ocean to a healthier status makes it necessary to take full advantage of all the existing resources and knowledge available. The challenge is in communicating these messages and stimulating the knowledge uptake and action from a vast range of stakeholders including scientists, entrepreneurs, educators, politicians, professionals and citizens in general.

Based on a recent review of OL in EU maritime policy, conducted in the framework of the H2020-funded Sea Change Project, it was concluded that "*EU maritime policy is largely based on the concept of OL, evidenced by reference to the OL principles and fundamental concepts either in the policy text itself or in associated communication products. This is although the term "OL" is not used in the policies. An exception is the use of the term in the 2013 Galway Statement on Atlantic Ocean Cooperation which builds on the Atlantic Action Plan as part of the Blue Growth Strategy*." (French et al., 2015).

For the OL movement to be truly transformative, all voices and all subjects need to be included. In this framework, the UNESCO-IOC initiative, which was launched in 2017, could provide a "voice" for a global OL movement, which extends beyond borders and nations and reaches out to the farthest countries that depend on the ocean and its resources. The "*OL for all: a global strategy to raise the awareness for the conservation, restoration, and sustainable use of our ocean*" initiative will encourage wider participation in the future of OL, including the engagement of individuals from different sectors of society.

Already existing worldwide initiatives that we can look at include the H2020-funded Atlantic Ocean Research Alliance (AORA), which coordinates marine science educators in Europe, the United States and Canada to better inform and engage citizens about the ocean's influence on them and their influence on the ocean. Through AORA, for the first time, there is now a transatlantic strategy on OL. The Transatlantic Implementation Strategy (TIS) drafted under AORA (Atlantic Ocean Researcg Aliance Marine Working Group Ocean Literacy, 2016), aims to consolidate existing efforts toward a proof of concept for Transatlantic Ocean Literacy (TOL).

COLUMBUS

The Horizon 2020 funded project, COLUMBUS[2], developed the *COLUMBUS Knowledge Transfer Methodology* (AquaTT, 2015a).

[1]Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive).

[2]COLUMBUS project received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement no. 652690.

Through 48 case studies, it has demonstrated its applicability for transferring knowledge from science to science, policy, society and industry in any sector and location (COLUMBUS partnership, 2018b). A unique aspect of knowledge transfer – that differentiates it from regular dissemination activities – is that it identifies an individual stakeholder's needs and plans its communication activities to suit this target's profile; thus, better ensuring the knowledge uptake and the generation of an impact. This targeted activity considers the individual's needs, mandate, technical background, preferences, and their circles of influence and concern. Hence, allowing a broader range of stakeholders to be engaged and action stimulated within them.

MATES

A newly funded project, the ERASMUS+ *Blueprint for a Sector Skills' Alliance in the maritime technologies*, MATES, is attempting to synergize knowledge transfer and OL to improve the maritime sectors' image and performance (I-Tech AB-Selektop, 2018; Mates partnership, 2018). MATES will be using targeted communication techniques to develop OL across a range of stakeholder groups and increasing the capacity of the industry to perform their activities sustainably, thanks to a more proactive knowledge uptake. Maritime stakeholders, including present and future employers and employees who are ocean literate, are expected to be willing to adopt more sustainable knowledge and technologies. The hypothesis being that more intense and efficient adoption of new knowledge and technologies offering more sustainable practices will have a positive effect on a sector's image and on the marine environment.

This article will present practical experiences – some of which were carried out within COLUMBUS – that illustrate a mutual benefit between OL and knowledge transfer. It also proposes how present and future OL activities – such as the current efforts in the context of the ERASMUS + MATES project – could build upon the rationale of COLUMBUS, reaching alternative audiences under a systematic approach.

THE COLUMBUS PROJECT AS A FLAGSHIP KNOWLEDGE TRANSFER INITIATIVE FOR THE BLUE ECONOMY

In 2012, the European Commission published the Blue Growth Agenda (European Commission, 2012) and, in 2014, released its communication relating to the Blue Economy and the need to realize the innovation potential of our seas and oceans for jobs and growth (European Commission, 2014). Both communications acknowledged the capacity of the marine and maritime activities to generate growth and employment on a sustainable basis and the need to boost innovation and knowledge transfer as a requirement to underpin such potential and guarantee sustainability. Europe's Marine Economy is not an exception comparing its situation with the whole innovation system within the EU, as far as similar weaknesses are observed: under-investment in knowledge; poor access to finance; the high cost of intellectual property rights; slow progress toward interoperable standards; ineffective use of public procurement and duplications in research; insufficient collaboration between the public and private sectors on innovation; poor transfer of research results into goods and services; and, a growing skills' gap (European Economic Social Committee [EESC], 2014).

In this context, the COLUMBUS project aimed at "ensuring that applicable knowledge generated through EC-funded science and technology can be transferred effectively to advance the governance of the marine and maritime sectors while improving competitiveness of European companies and unlocking the potential of the oceans to create jobs and economic growth in Europe on a sustainable (Blue Growth)" (AquaTT, 2015b).

Knowledge transfer was defined by COLUMBUS as "*the term for the overall process of moving knowledge between knowledge sources to targeted potential users of knowledge. Knowledge transfer consists of a range of activities which aim to capture, organize, assess and transmit knowledge, skills and competence from those who generate them to those who will utilize them*." This definition builds upon and synthesizes previous definitions, around the same concept. Most coincide in the requirement that the knowledge effectively moves from those who generate it to those who can effectively adopt and apply it. Transferrable knowledge can be found in a variety of formats and natures ranging from tangible intellectual property, products or patents to skills, know-how and expertise (Minshall, 2009). Knowledge transfer can involve a wide range of activities.

Knowledge transfer, as well as OL, always involves communication between individuals. For this to be effective and efficient, there is a need to properly understand the motivations of those who shall participate in the process, what the message(s) should be, how to transmit it (them), and through which means and when. Furthermore, actions for guaranteeing impact generation, as well as suitable mechanisms to measure this impact must be well planned and implemented.

The "*COLUMBUS Knowledge Transfer Methodology*" was designed to target any individual and so it can be applied to any individual irrespective of where they come from; any country or background, from industry, governance and policy spheres, from science, from education or from any other societal group. Whilst it was designed for the marine sector, it can be applied in any sector (although both COLUMBUS and MATES initiatives have the condition to respond to demands directly connected to the European Blue Economy) but it needs a good understanding of the context for application.

Three key concepts were defined as part of the COLUMBUS Methodology:

- Knowledge Output: A unit of knowledge or learning generated by or through research activity. They are not limited to *de novo* or pioneering discoveries but may also include new methodologies/processes, adaptations, insights, alternative applications of prior know-how/knowledge.
- Knowledge Output Pathway: A single step or a series of steps that are required to carry a Knowledge Output to its

Eventual Impact. It can include detailed mapping of the steps, the users involved at each step and their predicted role in the pathway to Eventual Impact.

– Eventual Impact: The ultimate end benefit of the application of the Knowledge Output. It is defined as an enhanced situation that is contributing to a political, industrial, scientific or societal need.

According to these definitions, COLUMBUS focused its efforts on collecting explicit units of knowledge (Koulopoulos and Frappaolo, 1999) which in the terminology of the project were named as Knowledge Outputs. These are articulated in lay terms to allow them to be transferred from any individual to another regardless of sector or background.

To explain the process that occurred, the European marine and maritime legislation was reviewed and combined with challenges identified by industry to describe key knowledge needs for nine groups of marine activities. Keywords from these identified knowledge needs were used to search the Marine Knowledge Gate (EurOcean, 2018) – a database containing information about national and European Commission-funded marine and maritime projects – as it was assumed that project abstracts containing these words might offer a solution to the identified sectoral needs. The selected projects were then reviewed for relevance to the sector. Knowledge was then collected from all of the projects deemed as most relevant and most likely to have performed research that might contribute to a solution for a sectoral need. The Knowledge Outputs that were determined to be relevant to the knowledge needs progressed to the "analysis" phase. Every Knowledge Output was analyzed: their application landscapes mapped, and target users identified. Where the analysis showed that there was a high potential for the application of the Knowledge Outputs to fulfill a knowledge gap, the Knowledge Output was transferred to the target user.

COLUMBUS was able to identify 967 projects which may have produced solutions that responded to the needs of nine marine and maritime activities. A total of 1,779 Knowledge Outputs were collected from these projects. Of these, 246 were prioritized and 56 knowledge transfer activities were completed. 48 of these success stories were released for public dissemination (COLUMBUS partnership, 2018b). The systematic approach followed by COLUMBUS can supplement the efforts of the OL community to reach new targets and levels of impact. To achieve OL and provoke a change in behavior – as observed in the COLUMBUS Knowledge Transfer Methodology – and to stimulate OL, the key messages, transmission channels and target audiences should be selected according to the specific pursued impact. Accordingly, OL can be considered a specific result of knowledge transfer, "science-to-all-society."

OL impact measurement was recently comprehensively studied during the development of an International OL Survey, which considers the broad scope of OL actions and stakeholders (Fauville et al., 2018b). Education, a community commonly approached by OL practitioners, represents a traditional pathway for knowledge transfer. Without evaluation, it is difficult to understand if knowledge from research activity has been taken up and applied by students (Jenkins and Zetter, 2003). The development of standardized methods to track and measure impact is, therefore, relevant and opportune. A systematic approach to achieve impact from knowledge transfer and OL processes can be of mutual benefit for efforts in both directions. Education and training communities and Blue Economy stakeholders can benefit from a combined approach and the MATES consortium will explore this further.

OCEAN LITERACY AND THE BLUE ECONOMY

There are several examples that can be drawn upon that illustrate the influence that OL can have on the wider society, with the Blue Economy stakeholders making up a key part of it.

In the past decade, United Kingdom citizens have seen that their actions can lead to policy change. TV chef Hugh Fearnley-Whittingst all launched the Fish Fight campaign to end discards in 2010. More than 870,000 individuals from 195 countries joined the campaign and 3 years later, European politicians voted to ban discards (Hugh Fearnley-Whittingstall, 2014). More recently, Surfer's against Sewage's Plastic-Free Parliament's campaign and Plastic Free Communities campaign were discussed in Parliament. These actions will contribute to a reduction of avoidable plastic packaging in supermarkets (Surfers Against Sewage, 2018). Films such as Sharkwater, Blackfish and The Cove are also a medium that is shown to influence policy.

Industries are also seen to be adapting their *modus operandi* by developing sustainability programs or embracing the circular economy. The Volvo Ocean Race, an internationally recognized sports event, was awarded the Sports CSR Campaign of the year at the International Sports Awards (Clegg, 2018). This award was given to celebrate Volvo Ocean Race's powerful message around marine plastics which influenced changes to business models and government policy as a direct result of the race. Clothing companies are increasingly using recycled waste found in oceans and rivers to produce yarn and some are even using algae for the outer sole of shoes (Carter, 2018). A football kit made from recycled ocean plastic has even been created for Manchester United Football Club by Adidas, and the sportswear brand has committed to using recycled plastic in all its products by 2024 (Hitti, 2018).

The large amount of experiences around marine litter (research, awareness, education, innovation experiences, etc.) in different domains and contexts (industrial, societal, public policies, etc.) could be considered to represent a relevant window of opportunity to systematize knowledge transfer and to exploit available Knowledge Outputs, including those for OL and general awareness. COLUMBUS also made some preliminary steps forward in this regard where Knowledge Outputs from the two FP7[3] projects MARLISCO (Marlisco Consortium, 2015) and CLEANSEA (Cleansea Consortium, 2015) were transferred by

[3]The European Union's Seventh Framework Program for Research and Technological Development (2007–2013).

one COLUMBUS partner, JÜLICH[4]. The first activity supported the formal adoption of marine litter related education units by teachers in public education centers in Germany. The second aided the design and development of local campaigns against ghost fishing gear in two United Kingdom localities (COLUMBUS partnership, 2018b). Another COLUMBUS partner, CETMAR, released a dossier compiling and classifying relevant past marine litter projects and outputs, making this information more easily accessible for future transfer and exploitation and supporting the follow up of the topic by the EC-JRC[5], who suggested the convenience of such a report (Fundación Cetmar, 2017).

The Horizon 2020 funded project ResponSEAble developed some OL products (Responseable consortium, 2018) built on the idea that environment-friendly practices and the adoption of available knowledge could lead to more competitive maritime industries, with a better image of their business. This idea was evoked by similar OL products developed for sustainable aquaculture and invasive alien species, among others. These and other examples that follow this approach will be gathered and used for inspiration in the new project, MATES.

The developers of new coatings and anti-fouling solutions, identified by COLUMBUS as promising transferrable Knowledge Outputs from EU funded research, were invited to a brokerage event in Brussels, organized by partners ECMAR[6], Aquatera[7], and CMT[8] (COLUMBUS partnership, 2018a). The Knowledge Outputs presented comprised different coatings and coating ingredients that can be used by the maritime industries to avoid damage caused by the attachment of marine organisms to vessels' hulls and marine devices such as offshore renewable installations or marine observation buoys. During the brokerage event, the antifouling properties of the different solutions were presented along with the results of preliminary field trials for some of the products. Many topics surrounding the sector were also discussed, such as the mechanisms used by some of the marine organisms to attach to the different types of surfaces; why the antifouling solutions should be achieved at no environmental cost; the environmental advantages to using an antifouling solution derived for more efficient energy performance. Although no *fit for all purposes* solution is yet available, the event followed to promote the interaction between scientists and industrials allowed the latter to more easily follow up the evolution of promising technologies and the opportunities to apply them to different markets; to acknowledge and understand the importance of environmental-friendly solutions; and, to be ready to collaborate to speed up the uptake of knowledge (COLUMBUS partnership, 2018b).

These examples show that OL has and will continue to have a significant impact on behavioral change in society, and when combined with knowledge transfer strategies, it contributes to a better predisposition of the knowledge users of all kinds, including industry, to uptake the best available, sustainable knowledge from research and innovation efforts. The MATES project will combine the practical approach developed by COLUMBUS for knowledge transfer activities with the most recent guiding principles and protocols for the implementation of OL activities emanating from the Horizon 2020 Sea Change project (McHugh et al., 2015). MATES will particularly explore those that can more easily aid connecting and interacting with the maritime industries and embedding and involving all the relevant stakeholders in the process, following the recommendations and expectations about the future of OL by IOC-UNESCO (Santin et al., 2017).

Compiling and organizing information about past practices will allow the extraction of lessons from the past. This is crucial to avoid duplication of efforts and inefficient use of resources. The MATES project represents an important opportunity to put the lessons learnt from the past and recommendations into practice, and to do it in a context which has not been fully explored in so far: A context derived from the mismatch between skills demands and training offers for the maritime activities; in particular, the shipbuilding and the off-shore renewable energy value chains.

This new project was designed to take advantage of the potential for synergies between knowledge transfer and OL as described in this article and to overcome some of the barriers for more successful achievements. As well as raising awareness about the relevance of the ocean to the maritime community, MATES will develop the "Skilling Strategy" for the maritime technologies' sectors in Europe addressing all education levels with a special emphasis on Vocational Education and Training (VET). Accordingly, it is hoped that MATES will result in a better predisposition of maritime employers to uptake an ocean literate labor force for improving the sustainability of their business performance and enhancing the sectors' image and competitiveness.

DIFFICULTIES FOR OL AND KT IMPLEMENTATION AND FUTURE CHALLENGES

Beyond synergies, there are also many barriers to knowledge transfer and some many coincide or have quite evident connections with those hampering the raise of the levels of OL in society, particularly in the industry. The OL community has comprehensively mapped the barriers for teaching Europe's young students about the ocean and has also gained an understanding of how these barriers are interlinked, including those that connect ocean education efforts and the Blue Economy, through marine careers and industry (Fauville et al., 2018a).

The FP7 funded project MarineTT (AquaTT, 2015c) ranked the barriers to knowledge transfer and innovation from marine research in Europe. These were later presented alongside a full review of challenges, opportunities and recommendations relating to outreach and dissemination (Reuver et al., 2016). From the works cited and from the further experience gained in projects like COLUMBUS and MATES, it is possible to identify

[4]PROJEKTTRÄGER JÜLICH.

[5]European Commission Joint Research Centre.

[6]European Council for Maritime Applied R&D.

[7]Aquatera.

[8]Center of Maritime Technologies.

some outstanding commonalities expressed in terms of shared shortcomings which point at relevant fields for future actions:

- There is insufficient awareness about the importance of the ocean for humanity in general, particularly for economic activities.
- Accessibility to knowledge has dramatically improved with Open Access policies, but access is not enough for the knowledge to reach out the wider community of potential users of the knowledge available. Ocean literate users will be prone to identify and uptake best available knowledge.
- There is a general lack of understanding on how to systematically and complementarily carry out knowledge transfer and OL actions, especially when the industry is targeted. Complementary approaches as proposed by MATES should be further explored.
- The basic concepts and the specific lexicon used to refer to OL, knowledge transfer and science communication are commonly mixed up and used on a loose basis. Sometimes a specific term becomes best-selling and this frequently leads to misuse or overuse of such terms while other relevant ones are abandoned (Uyarra and Borja, 2016).
- The connections between stakeholders and practitioners from the different spheres or sectors – science, education, industry, policy, and the wider citizenship – are yet insufficient. It is difficult to break the work-in-silos culture. Long-term multi-stakeholder initiatives should be further promoted.
- Motivations and potential incentives of and for the different stakeholder groups are different and not always fully known and acknowledged from one group to another. Analysis is needed for efficient approaches to knowledge transfer and OL.
- Impact generation and measurement is essential for both knowledge transfer and OL efforts. However, there are limited or no repercussions for projects that are not achieving their expected impacts, and most commonly their socio-economic targets.
- Knowledge transfer and OL activities need a strategic and systematic approach for their implementation and thus, they need to be planned, monitored and evaluated once executed.
- Knowledge transfer and OL require skills, time and resources. There is insufficient investment on knowledge transfer, communication and/or OL activities. These activities are often considered *secondary* components of the research life-cycle, at least when the resources for their implementation are assigned.

CONCLUSION ABOUT THE SYNERGIES BETWEEN OCEAN LITERACY AND KNOWLEDGE TRANSFER

The most common playing field for the OL movement in Europe, so far, has been within the education sector and the general public. In fact, the work done by OL practitioners has connected research and education and translated some of the best available marine knowledge into didactic contents, comprehensive for students and trainees of all ages. OL, as well as marine knowledge transfer, represents a specific service application of marine knowledge management and its potential to have an impact on the sustainable development of the marine economic activities, whilst already broadly recognized (Santoro et al., 2017), needs to be further developed.

Recent efforts in marine and maritime knowledge transfer and OL have provided a more systematic approach for both types of activities, facilitating the understanding of the required steps by any practitioner (AquaTT, 2015a; McHugh et al., 2015; Fauville et al., 2018b). They have also enabled the exploitation of potential synergies, especially in reaching the Blue Economy stakeholders' communities. OL and knowledge transfer services can be combined to provide a permanent route for state-of-the-art marine science to be delivered through a diversity of means and formats (seminars, workshops, conferences, social media, massive online courses, etc.) to these stakeholders (Amaratunga and Senaratne, 2008). It is, therefore, assumable that good practices and insights in marine and maritime knowledge transfer can benefit future OL efforts and, *vice versa*, materials and lessons learnt from past experiences can be shared between the two communities of practitioners.

The quality of the answers of individuals about a given matter is directly related to the amount and quality of knowledge they hold about such a matter. Increased education and skills development surrounding the ocean and the knowledge transfer practices (a) supports the synthesis of relevant knowledge, which is essential for a better understanding and for making informed decisions; (b) allows for creativity and innovation and for the development of the so-called "21st Century Skills" (Partnership for 21st Century Skills, 2015); and, (c) unveils for all, the valuable services from the marine environment. Thus, through developing OL in Blue Economy stakeholders and through the systematization of marine knowledge transfer, the environmental performance of marine and maritime sectors is expected to improve. The enhancement of the maritime sectors' image will come as a consequence.

The MATES project represents an important opportunity to put the lessons learnt from the past and these recommendations into practice. This new project is designed to take advantage of the potential for synergies between knowledge transfer and OL practices and practitioners as described in this article, and to overcome some of the barriers for more successful achievements. The integration of OL aspects as a horizontal component of the MATES' strategy design, will allow for the identification of most suitable pathways and action lines for an eventual impact consisting in a better predisposition of maritime employers to uptake an ocean literate labor-force and state-of-the-art marine knowledge and ultimately, to enhance the maritime sectors' image. MATES has foreseen specific efforts for the roll out of the resulting strategy beyond the project execution and at different geographic levels (EU, Member States and Regions). The strategy implementation will be addressed with the involvement of multiple stakeholders: from the industry, from the education and academia sectors and from the administrations.

The MATES partnership is already a multi-stakeholder network committed to undertake the Strategy and to scale up successful pilot experiences. This legacy will be promoted toward the wider marine and maritime communities, especially, at EU level. Achievements, however, will have a broader effect because MATES' partners as well as, in general, the EU maritime stakeholders are strongly interconnected at global scale.

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All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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