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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

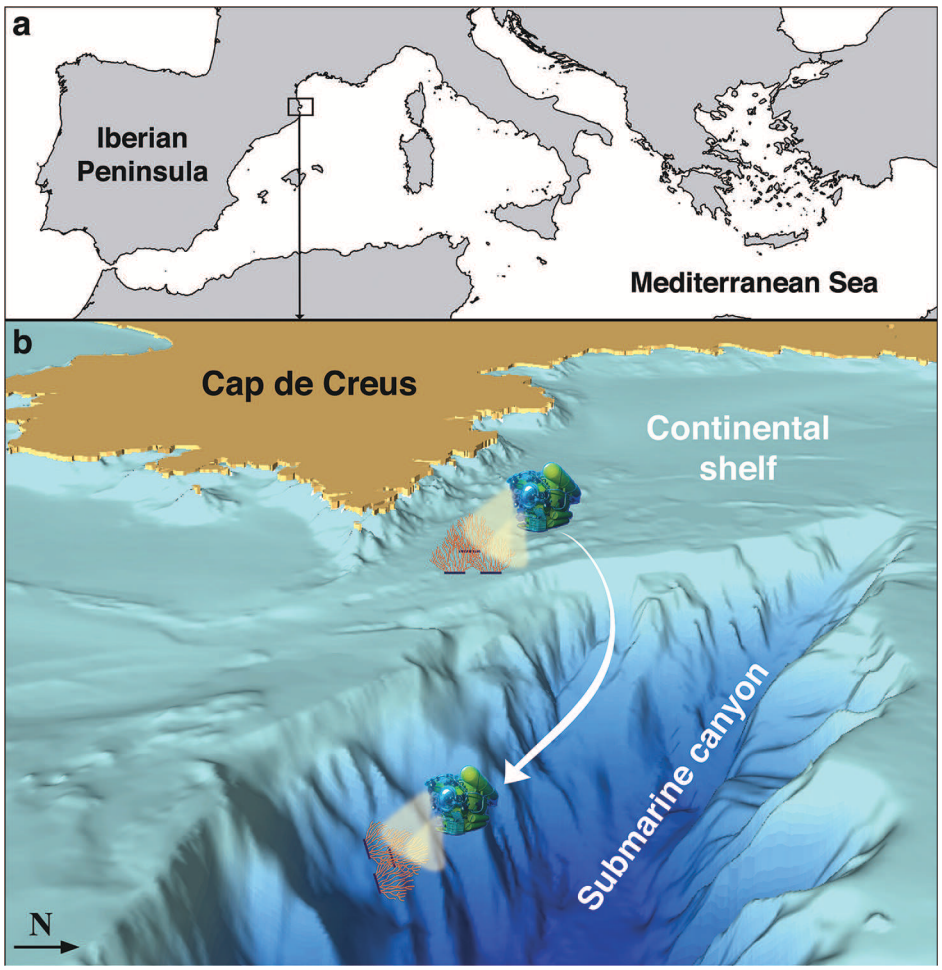

FIGURE 2 | (a) Location of Cap de Creus marine area, at the end of the Gulf of Lions in NW Mediterranean. **(b)** Recreation of the path performed by the manned submersible in Cap de Creus during the virtual dive, starting on the continental shelf and moving towards 400 m depth by the southern flank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

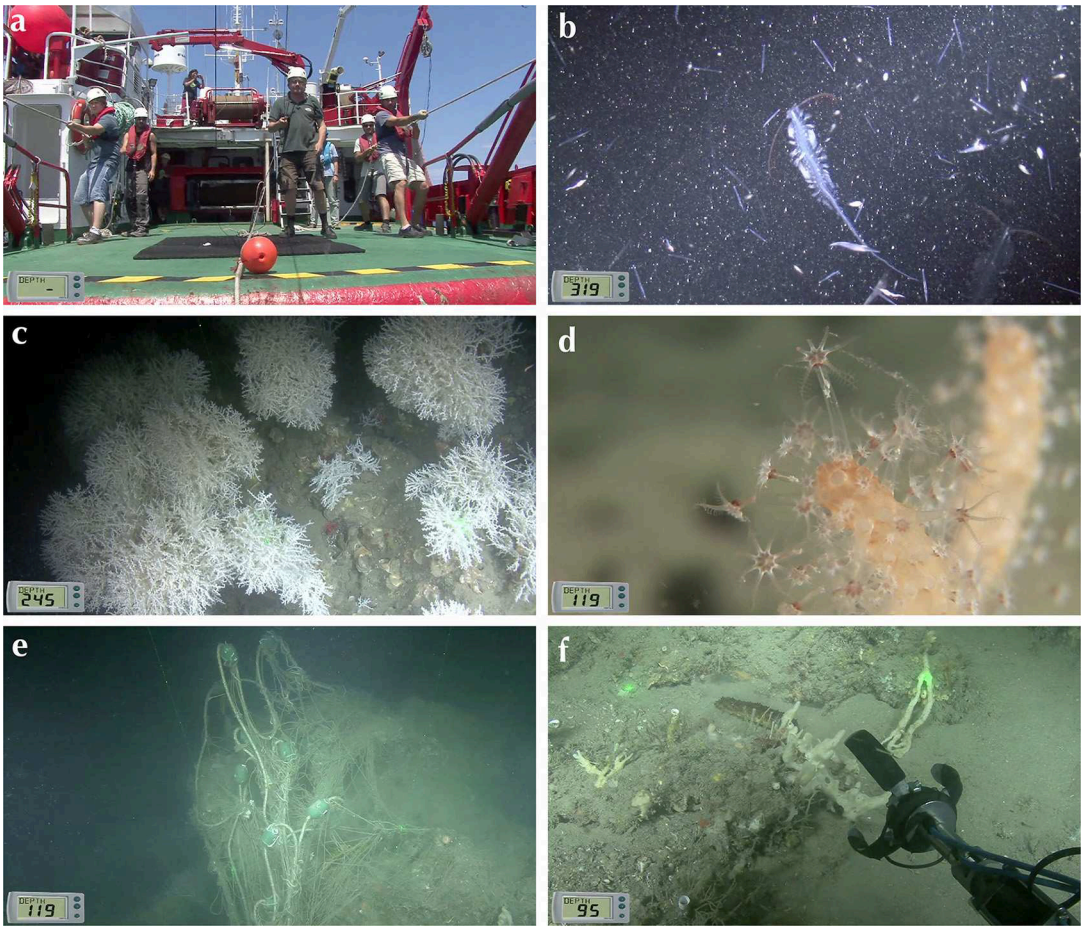

FIGURE 3 | Snapshots showing different moments of the virtual dive: **(a)** The deck of the R/V Garcia del Cid and its crew preparing themselves for the deployment. **(b)** At the deepest point, different plankton lifeforms can be observed in the water column. **(c)** Large colonies of the cold-water coral *Madrepora oculata* 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,

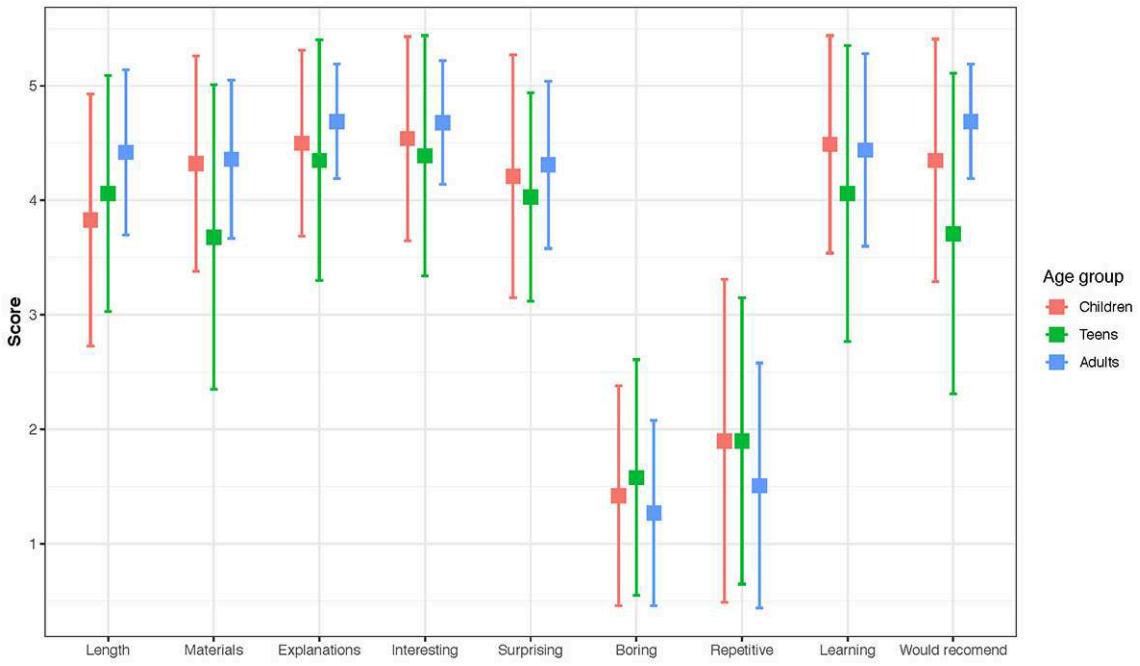

FIGURE 4 | Results (avg. ± s.d.) of the nine closed-ended survey questions among the three different age groups: under 12 years of age, ($n = 219$), teenagers aged 12–17 ($n = 33$) and adults ($n = 67$).

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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