
RESEARCH AND EVALUATION

Role-Playing to Foster 'Deep-Sea Exploration' Through Active and Virtual Learning: A Class-Design for Colombian Higher Education

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Deep-sea exploration is without doubt one of the most challenging-to-perform activities on Earth, as it faces natural limitations and it strongly relies on technological developments. Fortunately, advances in technology that are shaping the way we explore the deep sea can now be used to foster an innovative classroom environment. In this article we introduce a *Deep-Sea Exploration* graduate-level course with a foundation in active and virtual learning. Because virtual education is setting the pace in current times, here, we share the outline of this course with specific activities that can be used to engage and connect students from multidisciplinary backgrounds in contexts where barriers to perform deep-sea exploration are stronger. Students are expected to take three roles, researcher, entrepreneur, and explorer, to account for the intrinsic relationship between deep-sea scientists and other career practitioners. All roles prioritize collaborative work among students and motivate them to be creative, autonomous, and innovative. The course methodology exposes students to the deep-sea community through challenges such as grant proposal writing (Researcher), business idea innovation tanks (Entrepreneur), and novel discovery annotations on deep-sea exploration cruises streamed live via telepresence (Explorer). Beyond receiving information provided solely by lectures and readings, students in *Deep-Sea Exploration* use tools to build on their knowledge and to spot real-world opportunities for professional and sustainable community growth.

Keywords: Deep-sea exploration; telepresence; Marine Biology; Active learning; Virtual education

Introduction

The deep sea (more than 200 meters in water depth) comprises the largest biome on Earth and the last frontier for exploration on this planet (Koslow, 2007). New opportunities for innovation and sustainable development are plentiful in the deep. Yet, budgets for space exploration exceed thousands of those for ocean exploration. About 500 humans left Earth's orbit over the past 53 years (Shelhamer, 2017), while only 12 people reached the deepest place in the ocean; nine of them within the two last years, thanks to Victor Vescovo's Deep Sea Vehicle (DSV). Without a doubt space science has inspired hobbyists and youth around the world. Paradoxically, space exploration rhetoric could hold immense engagement potential for deep-sea exploration, where scarce advances in innovation and technological capabilities have transpired over decades. The oceans already provide humanity with many resources, but the deep oceans have been noticeably overlooked because of their inaccessibility. Turning the spotlight on deep-sea ecosystems comes to be particularly important as the seafloor harbors vast untouched resources parallel to natural resources that provide us with food, energy, and raw materials and take part in climate regulation and productivity at the ocean's surfaces. Today, rapid industrial development and growing human pressures in the form of climate change, deep-sea mining, non-sustainable resource extraction, land-based pollution, and habitat degradation are the most impactful threats to the seafloor health and productivity (Victorero, Robert, Robinson, Taylor, & Huvenne, 2018). Hopefully, advances in ocean robotics and the combination

of remote and *in situ* ocean observations together with free and open data sharing and multi-stakeholder contributions by international scientific institutions and governments are opening exciting opportunities for students to learn, develop, and connect with real-world scenarios. Additionally, huge gaps in scientific capacity and capability around the world will require that we fundamentally change the way we train and employ researchers from developing countries (Pendleton, Evans, & Visbeck, 2020). Above all, we need to dramatically expand the breadth of disciplines that are directly involved in new transdisciplinary ocean research. We believe one path of action to support growing in these areas is promoting a multidisciplinary understanding of ocean processes in education. To do so, we propose a solution-oriented class design for deep-sea research combining exploration, technology, and business viewed from an ecosystem services perspective. Our class design aims to yield innovative ideas, creation or improvement of existing marine technologies, and fundamental knowledge in the context of sustainable development and human-ocean interactions, especially where there are further barriers for developing nations to perform deep-sea exploration or fledgling research programs subjected to small budgets attempting ocean science in the deep sea.

Deep-Sea Exploration aims to engage young researchers and students with the opportunities for discovery and innovation that await on the Colombian seafloor. Colombia is perhaps the country with the highest marine biological diversity in South America. Nonetheless, marine science in Colombia has developed slowly for 35 years, with the first paper published by Colombian scientists in an international journal in the late 1960s (Díaz & Acero, 2003) and with an even newer research of the deep-seafloor, mostly based on opportunistic information from the oil and gas industry (Acero P, Polo-Silva, León, & Puentes, 2018; Dueñas et al., 2019; Guerrero-Kommritz, Cantera, Puentes, & Leon, 2018). Consequently, the contribution and importance of Colombian deep-sea resources to the national economy and the development of its coastal zones falls short, resulting in a low level of maritime culture among the population and failing at granting scientific information about oceanographic and biological opportunities in the deep sea that would meet societal needs in Colombian communities.

Latest publications on deep-sea megafauna in the Colombian Southern Caribbean have laid out several species imagery records setting these images as basis for new species diversity exploration and ecological information (Acero et al., 2018; Victorero et al., 2018; Borrero-Pérez, Dueñas, León, & Puentes, 2020), but mostly performing Remotely Operated Vehicle (ROV) video surveys and towed camera transects, only. However, a vast majority of the ecosystems in bathyal, abyssal, and hadal zones are still unexplored, while the pressure to license areas of the deep ocean are only intensifying (Borrero-Pérez, Dueñas, León, & Puentes, 2020). On the other hand, several explorations and new data on Latin American countries' deep-sea territories have come out from oil and gas companies (Borrero-Pérez et al., 2020; Dueñas et al., 2019; Grijalba-Bendeck et al., 2019). These companies also fund programs and consortiums at universities to conduct basic research, which could apply to the industry in the future. Henceforth, it is important to foster social-ecological synergies that promote the integration of social and environmental sciences in the context of global change by encouraging and nurturing the implementation of more democratic and less impactful activities on the seafloor far from the traditional ways of exploitation. We suggest that a diversification of the stakeholders dominating seafloor maps and megafauna data could favor this quest. Moreover, we underline that Colombia, as a megadiverse country with access to two oceans, lacks a deep-water exploration program. Considering the current scientific capacity of Colombia, including financial and logistic limitations, short- and mid-term research plans and programs for deep-sea exploration are only being touched by governmental and official institutions by a very selected group of researchers. In Colombia, in particular, there are very limited options for science students to enroll in deep-sea research. The lack of ocean studies and multidisciplinary groups addressing seafloor exploration opportunities in national waters is paradigmatic. One of the strengths of this class design is linking students in science to students in policy-making spheres to achieve more efficient management and cross-sectoral cooperation and work on class projects that address the planning and management of deep-sea ecosystems, pristine and undiscovered in both the Colombian Pacific and the Caribbean Sea.

Deep-Sea Exploration is the first graduate-level educational effort (University of Los Andes, Bogotá, Colombia, and the Fulbright Colombia program) in the country addressing marine technology and exploration of the national seafloor with coursework directed not only for marine scientists, but also for engineers, business, design, and communication students. More importantly, *Deep-Sea Exploration* aims to provide young scientists and stakeholders at a local and international scale with the right scientific information, multidisciplinary background, and international references that enable good decision-making

for future management agents of the Colombian seafloor. During the class, we followed similar active learning practices from ocean-related sciences (Kunieda, Kashima, Kido, & Murai, 2017; McConnell et al., 2017), where students exert three key roles in the history of deep-sea exploration, researcher, entrepreneur, and explorer, under a learning environment in which the student is required to perform actively toward the accomplishment of a main goal or task per module. These proficiencies are intended to first, facilitate an interactive capability to conduct experiments using data streaming in real time. This meets environmental and societal needs present in Colombia for acquiring the necessary skills to increase and share ocean data promptly. Second, young professionals begin work on closing the communication gap between scientists and non-scientists actors in deep-sea exploration and resources management.

While doing so, role-playing seeks to immerse students in real-world scenarios where they would need to establish, for example, marine protected areas (MPAs), design and prototype innovative technologies, and transfer scientific literacy on sustainable management, innovation, and sustainability to create deep-sea exploration dynamics that are protective of natural untouched resources. All of this is achieved in a virtual learning environment oriented to collaborative tasks that are strongly group-related and demand coordination skills and brainstorming.

Deep-Sea Exploration: Challenges For A Virtual Learning Environment

Understanding the hurdles involved in conducting science at sea, especially when it comes to the deep sea, brings students to appreciate that science at its core is also about observing, questioning, and solving the unplanned and the unknown. In Colombia where the development of the curricula is still subjected to very few opportunities for research, these opportunities tend to occur at the end of the undergraduate program (Badillo, Miranda, Torres, & Guzmán, 2020). In order to move away from traditional in-class evaluation methods, we valued collaboration among peers, both face-to-face and electronically, in order to help students receive feedback about their understanding of deep-sea research and exploration-related methodologies and technologies. This was accomplished through a blended learning program modality, that included autonomous e-learning, written assignments, in-class workshops, and occasional quizzes that together provided students frequent opportunities to make their current ideas visible and refine their understanding when needed (Harris, Bransford, & Brophy, 2002). Additionally, we highlight that the role-playing dynamic reinforced a community-centered learning environment that encouraged students to learn from one another, which resulted in stronger, more cohesive projects using every different background knowledge.

From a wider perspective, *Deep-Sea Exploration* role-playing oriented methodology attempts to reduce the gaps present in tertiary education research opportunities by organizing students' personal backgrounds and knowledge around three key roles: explorer, researcher, and entrepreneur. This approach fosters a supportive learning environment to enhance knowledge and thus opportunities for sustainable and innovative deep-sea exploration in Colombia. This is particularly useful when it comes to rectifying the vision that young scientists have about what it means to construct a career around the deep sea.

Integrated research is needed to assess the human and environmental risks of traditional routes of exploration and exploitation, like the one Colombia is so far compelled to perpetuate. To encourage more sustainable production and consumption and other governance regimes, we engaged students in three deep-sea roles, to foster critical thinking on how to address deep-sea challenges in Colombia. These three roles were not merely a class exercise, but enabled a professional pathway to increase interactions between the academic and societal communities (Visbeck, 2018).

During a period of 16 weeks, the *Deep-Sea Exploration* class challenged students to engage in three modules focused on each of the three roles. Students were expected to go through every module synchronously and finalize each module with a closing project specifically designed for each role. An equal amount of five weeks was allocated for each module. The main goals during the researcher, entrepreneur, and explorer modules, respectively, were: (1) to write a research proposal on a major deep-sea research question, (2) to depict and outline an innovation or business proposal inspired by a deep-sea challenge and (3) to engage in authentic deep-sea exploration using telepresence (**Figure 1**).

Furthermore, introductory activities included readings on how to improve scientific writing in English. We primarily used the reference the book *Stylish Academic Writing* (Sword, 2012), which the students read before proofing their writing assignments on the book's online tool The Writers Diet (<http://writersdiet.com/test.php>), designed to provide feedback to the students' writings in standardized diagnostic categories –“lean,” “fit,” and “trim,” “needs toning” or “heart attack.” Each module presented a demanding and creative

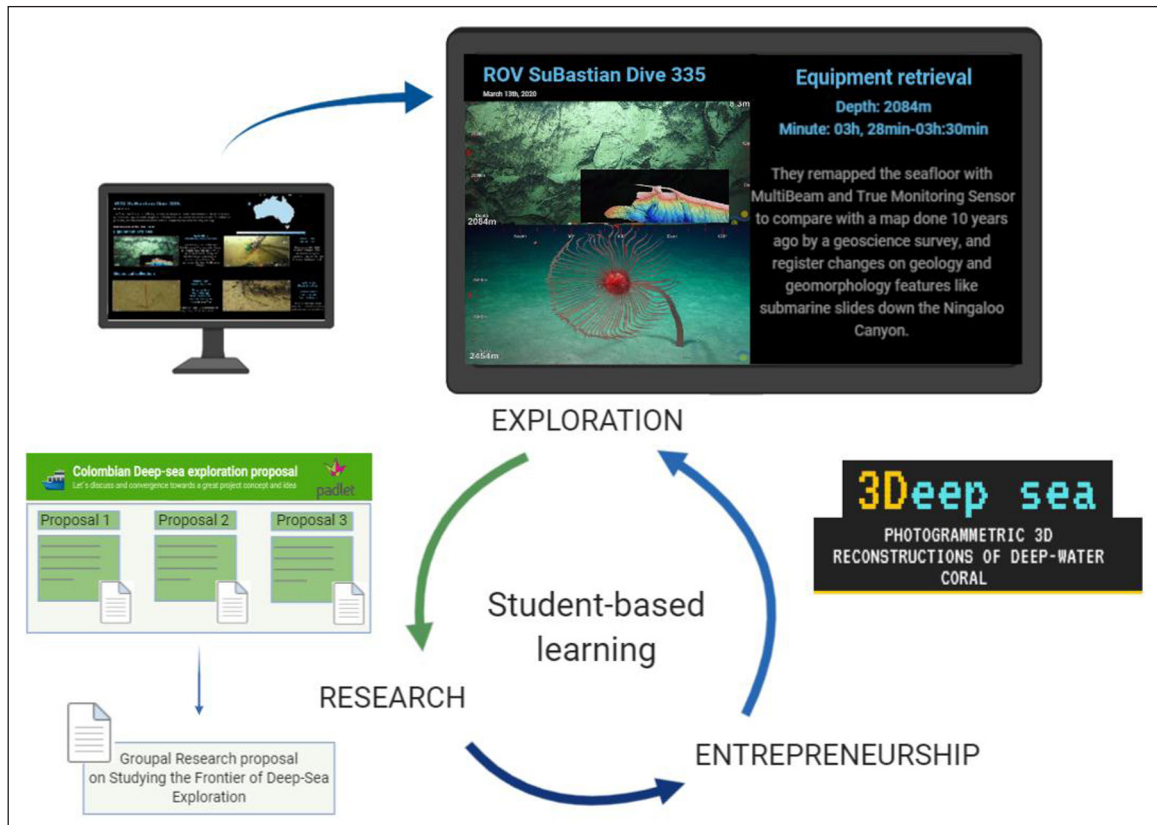


Figure 1: Examples of completed assignments from students as they navigated the roles of researcher, entrepreneur and explorer. Exploration: sample infographic with the daily datalogger of the telepresence exploration in real-time. Entrepreneurship: sample prototypes of business ideas. Research: process diagram of the construction of a group research proposal from individual works using the online application Padlet (es.padlet.com) to share ideas.

assignment. As researchers, the students wrote a research proposal for filling an ocean exploration gap in the Colombian Caribbean, intended to foster skills for scientific writing, capacity building, and networking. As entrepreneurs, coming out of their comfort zone, the students identified new business opportunities for the deep sea. This module included working on a business model Canvas identifying products, investors, and methodologies in their projects, and concluded with a business “pitch” presentation. Last, as explorers, the hallmark of the class engaged students in real-time deep-sea exploration through telepresence, a near-real explorer experience. Summed to the diversity of the students backgrounds, the transition through the three roles equipped students with skills to help them navigate the barriers that may require dealing with different disciplinary behaviors (Claudet et al., 2020). The *Deep-Sea Exploration* role-playing dynamic brought science, engineering, and business students out of their comfort zone to learn the basics of different but critical disciplines to safeguard Colombian deep-sea resources, untouched and vastly unexplored to date.

On another note, we emphasize that deep-sea telepresence is a powerful tool for active learning, providing students an authentic research experience at an undergraduate level. Unlike other learning environments, telepresence has the potential to allow students to interact with the real world with all its richness and unpredictability, rather than with a world that was designed for a controlled learning experience. By following a live expedition via telepresence, the course favored a maximized learning environment where students addressed tasks with an emphasis on research and exploration by documenting new species and understanding marine technology uses and limitations. Simultaneously, telepresence served to connect students with real scientists and engineers at sea on social media (e.g., Youtube, Instagram and Twitter), broadening the learning environment of the class to informal scenarios. This was valuable to students, as many reported to have incorporated deep-sea-related social media as part of the information they consume on their phones on a daily basis. Accordingly, we believe integrating telepresence into the course fostered implicit learning, which will enable students to learn about language and people across their lifespan (Bransford et al., 2014).

Researcher Module

The researcher module was designed to educate students on how to effectively write a research proposal. To address this task, the students researched deep-sea topics on their own then the whole class shared information using the citation software Zotero for literature search and management (Center for History and New Media, <https://www.zotero.org/>). Students were introduced to peer-reviewed papers (e.g., Danovaro, Snelgrove, & Tyler, 2014) and guided by in-class discussions to develop scientific thinking into their individual research proposal. Additional insights on deep-sea research included lectures on deep-sea biology and connectivity using state-of-the-art methods (Baco et al., 2016; Dueñas et al., 2016; S. Herrera, Shank, & Sánchez J. A., 2012; Quattrini, Baums, Shank, Morrison, & Cordes, 2015).

Successful grant proposal writing embraces a long-lasting requirement in the professional career of any scientist. Accordingly, this module concluded with a round-table discussion activity where students collaboratively wrote a proposal on the major questions in deep-sea exploration and ecology (Danovaro, Snelgrove, & Tyler, 2014) applied to increasing knowledge in Colombian waters. The proposal was written for a specific funding agency (Schmidt Ocean Institute) that funds telepresence-enabled expeditions worldwide. Even though this was only intended as a class exercise, after extensive peer-review rounds with the students and professors the group started working on a main proposal in pursuit of proposal submission for next year's SOI call (<https://schmidtocean.org/apply/apply-support-2020/>). After an individual attempt of writing a complete idea proposal using 'The Writer's Diet' and references in Zotero, we performed synchronous discussions (Blackboard Collaborate) to choose, by consensus, the best proposal ideas. The four best proposal ideas were selected and included as research objectives in a group proposal with all students contributing to a collective writing effort. In that spirit, the grading scale of the research activity subscribed closely to the call guidelines and evaluation criteria from the Schmidt Ocean Institute.

Entrepreneur Module

After the 2012-Rio +20 Conference on Sustainable Development, the term 'Blue-economy' was recognized as capturing the enormous economic potential of the oceans. Scientists have the opportunity to use their expertise to redirect the prevailing harmful practices in the industry and legislative landscape to improve knowledge and sustainability assessment in public decision-making. However, scientists rarely consider taking a career in industry or starting their own business, an issue that is rooted in education, where the traditional academic path is presumed as the only congruous option.

The entrepreneur module is designed to introduce the students into innovative thinking oriented to spot and solve the trade-offs between sustainability and optimality in "business as usual" markets. Here, students worked in pairs on a business proposal. Students first watched videos by and about Sylvia Earle, a role model of an entrepreneur scientist. Then, using a nine steps Business Model Canvas (Osterwalder & Pigneur, 2012; Osterwalder, Pigneur, & Tucci, 2005), they developed potential business projects. By choosing a problem within the deep-sea community and working on how they wanted to tackle their challenge of choice, students conducted group projects that reinforced observational and creative skills. This module incentivized a multidisciplinary think tank for entrepreneurship ideas. This provides a safe space to cultivate science-based knowledge and beliefs that shape students' and entrepreneurs' propensity to pursue social and environmental aims. By investigating the existing downsides of non-regulated economic growth, based on consumption and stressing the interdependence of economy and sustainable management, deep-sea ecosystems can be understood as either finite or renewable natural systems. The business innovation tank was done in parallel with the research proposal activity and focused on advancing ocean research technologies, practices, and methods. Working on the projects concurrently enabled the students to develop and design business ideas for sampling and processing biological data from the deep sea. Some of the products included a microarray identification tool to process genetic material *in situ* and point clouds that allow mapping and reconstructing hard-to-extract specimens, such as sponges and corals, using photogrammetry software from ROV-based videos. After some feedback from the instructors and classmates, students presented their final ideas as a business pitch either in a video or podcast format. Some of the outstanding class products can be found here: "Deep-sea explorers from home" (available online in <https://youtu.be/YHGLi3m1Ud0>), and "Deep-Sea Microarray Identification Tool (DESMIDETO)", podcast available (<https://www.youtube.com/watch?v=yRQJhImbDu8&feature=youtu.be>).

Ultimately, the entrepreneurship module enabled students to create and work on business ideas intended to fill gaps within deep-sea exploration activities.

Explorer Module

Using space technology, humans have explored the great depths of the sea in a manned and remote way, creating opportunities to follow real-time expeditions from the deep ocean (Van Dover, German, Yoerger, Kaiser, & Brothers, 2012; Stephens, Pallant & McIntyre, 2016). Despite these outstanding technological achievements, there were more ambitious deep-sea expeditions during the 19th century than now (Alcock, 1902; Thomson, Murray, Moseley, Buchanan, & Von Willemoes-Suhm, 1876). Notwithstanding, expeditions at the time would be subjected to the beginnings of bathymetry, dredging, temperature and salinity measurements, and mapping, and therefore provided only a glimpse of the deep seafloor. As an introductory activity to deep-sea exploration, we started the class with a collective activity to reconstruct the timeline of deep-sea expeditions. The deepest region of the ocean, the Challenger Deep, was discovered in one such expedition by the HMS *Challenger*. During this activity, students chose a taxonomic group of their choice and selected five new species first described from collections during the HMS *Challenger* expedition. They constructed an infographic on Padlet using original images of the species along with information about their life history and their current status. They also included additional notes available in the expedition volumes to frame morphological data on the species accompanied by other details, including environmental factors, geographic location, date, and methods of collection. This assignment also promoted learning of systematics, taxonomy, and zoology—fields that are often not taught at the collegiate level.

After students were familiarized with historic deep-sea expeditions, they followed a deep-sea expedition in real-time (i.e. “Illuminating the Ningaloo Canyons”) via online streaming over the course of three weeks. Together, they created a daily blog of discovery activities and ongoing projects using the timeline format on Padlet. Padlet allowed the instructors to visualize and organize students’ progress throughout the expedition, while students benefited from having access to a permanent database of described species by their peers that supplemented the fleeting oral conversation of in-class discussions. The activity consisted of each student choosing two findings, one biological and one geological, and making an infographic that included images directly obtained during the expedition, details on the depth and other environmental conditions, technical description on the finding, significance of the observation, and additional information on the topic. The expedition via telepresence brought one essential perk to the learning process: real-time interactions between researchers onboard the ship and students, who were able to ask questions and feel part of a more extensive community interested in deep-sea exploration. Furthermore, Padlet as a classroom communication technology was a valuable tool, as it allowed both the instructors and the students to have in-sync visuals and comments throughout the expedition, which could be further discussed during class sessions. These results could have to do with the fact the content addressed during the explorer module required image and sound interaction.

Conclusions

“You can only inspire when you give people a new way of looking at the world in which they live.”

Robert Ballard

We wanted to share and expand the reach of our class for several reasons. First, we believe it to be a successful approach to virtual learning, which deeply engaged students (and faculty). Second, we believe that we had an immense opportunity to explore online teaching tools and methods and turn our gaze to the weaknesses in the educational system that perhaps became more apparent due to the COVID-19 pandemic. By sharing this course content and methodology, we aim to encourage active learning by example. Teaching, especially on virtual platforms, needs to diversify the traditional lecture and guarantee that learning environments are engaging, which can help to achieve high-learning goals. This course showcases active learning to be of worth when instructing science—never going against its rigorous and methodological course of action—but by putting scientific thinking in other scenarios where it is not commonly exerted. Promoting joint capacity building and innovation is key to enhancing local cooperation and uptake of relevant science into policy actions in nations where the deep sea remains untouched.

Deep-Sea Exploration offered students three professional profiles as a way to engage in the class. Students participated in ocean exploration and were exposed to cutting-edge technologies. The students, as hands-on researchers, searched for scientific literature using tools for reference management and collectively developed a grant proposal. As entrepreneurs, students identified innovative businesses and opportunities in the deep sea. Through telepresence, the explorer activity provided students with a genuine background on deep-sea expeditions. The role-playing broadened engagement of all three simplified different backgrounds

our students represented, which made collaborative scientific work more trustworthy and marked a new departure for how to address some of the challenges that Colombia confronts in terms of human capital development, scientific exchange, cross-cultural dialogue, and multidisciplinary engagement. We stress that this exercise will only be pervasive in the national decision-making arenas if they are informed by sound science and followed by innovative financial strategies and if they are enacted with the support of a society that shares those values and supports those changes. Improvements in ocean literacy and education will help in gaining this necessary societal support (Claudet et al., 2020).

Today it is possible to follow real-time expeditions from the deep ocean using telepresence. Ten years ago, this was only possible at a few institutions that had 2 GB internet, which used complicated connectivity and advanced academic networks (e.g., Internet2, Geant). Recent developments in data encryption and transfer make it possible to stream expeditions even through a smartphone (e.g., via YouTube), offering the opportunity to large groups on land to witness new underwater discoveries as they occur through the lens of an ROV. Telepresence from deep-sea expeditions greatly impacted students, who expressed openly that their view of the deep ocean changed completely by the end of the course.

In Colombia, this type of learning is still new and unfamiliar. Far from being a slow process, active learning (e.i. adaptive and contextualised learning pathways presented in the three modules) and early exposure to real science taking place (e.g., telepresence expedition, collaborative proposal) show the undeniable advantages of switching from the traditional lecture to new learning opportunities that virtual environments have to offer. Learner engagement was measured as genuine interest and interaction in the class modules mostly reflected by the frequency of questions, demonstration of persistence, and attention and participation in the three principal tasks. Ultimately, this course increased student engagement by increasing student activity. We found that encouraging students to put into practice their personal knowledge and skills ensured student-directed learning in which students plan and solve problems by interacting with others and take control of the pace of their learning. In fact, three-quarters of the class population declared that collaborative work contributed to their learning process and agreed that the course encouraged an autonomous learning capacity (see Supplementary Material). Formative feedback requested more lectures and material support for tasks development. Perhaps it is still necessary to include a few lectures in courses, as carried out in *Deep-Sea Exploration*, but interactive teaching methods as the ones suggested here connect people through real-world examples whereby they can become active learners and transform individual skills into real contributions to the field. This type of approach takes the student directly from a passive participant in class to a fully engaged learner that facilitates the development of their own knowledge, skills, and attitudes. Underlying approaches to active learning in this course methodology maintained highly engaged students who transcended classroom obligations to become deep-sea researchers, entrepreneurs, and explorers.

Additional File

The additional file for this article can be found as follows:

- **Supplementary Material.** Role-playing to foster 'Deep-sea Exploration' through active and virtual learning: a class-design for Colombian higher education. DOI: <https://doi.org/10.5334/cjme.55.s1>

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Competing Interests

The authors have no competing interests to declare.

Author Contributions

Juan Armando Sánchez and Andrea Quattrini designed the course content. Adriana Patricia Rodríguez-Bermúdez made the figure. Sánchez, Rodríguez-Bermúdez, Lorena Neira-Ramírez, and Quattrini wrote the draft and approved the final version.

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