

## Boosting adults' scientific literacy with experiential learning practices

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### Abstract

*Working as an interdisciplinary team, from the departments of Education and Biology we organized a short experiential learning seminar followed by a hands-on workshop for the promotion of citizen scientific literacy. Participants were adult lifelong learners enrolled in University programs, and others were adults interested in scientific activities without a motivation towards continuous learning. Through a teaching dynamic based on learning science by doing science, they could make close contact with the research procedures in scientific laboratories and learn about the use of DNA to identify unknown fish species. The data collected about their learning gains in this science literacy experience showed that elder lifelong learners found the basic scientific concepts more difficult to understand than the non-lifelong learners, but were more motivated to engage in science education activities than the latter, which makes them a very interesting potential group to recruit for citizen science initiatives..*

**Keywords:** Citizen science, hands-on lab practice, lifelong learning, science literacy, volunteering engagement



## Introduction

Nowadays, we live in a globalized environment subject to permanent changes. Science describes, interprets, and sometimes drives those changes. In different educational environments, experiential education (Beard, 2018; Lowery & Jenlink, 2019) tries to encourage scientific literacy by relating science to the student's life experiences (Aikenhead, 2006), favoring their active participation in scientific inquiry (Waldrop, 2015), learning science by doing science. In schools or socio-educational spaces, in formal or non-formal education settings, through scientific and informative publications or through digital platforms, what really matters is to design and carry out learning experiences and opportunities to develop the scientific literacy of the population (Cronin & Messemer, 2013; Roth & Lee, 2016). Bypassing the difficulties of managing a shared definition (Liu, 2009), what does seem clear is that scientific literacy focuses on providing scientific knowledge to people, for them to acquire basic skills to understand the progress and impacts that science has on their lives and on the environment, and to develop positive attitudes towards it. It also has the aim of equipping them with the competences necessary to critically analyze science's relationships with their own life experience (Croce & Firestone, 2020; Sharon & Baram-Tsabari, 2020). The very idea of scientific literacy involves teaching science to everyone, without exclusion, so that citizens can build their own opinions based on objective facts and participate responsibly in decision-making processes on issues that affect their lives (Croce & Watson-Vandiver, 2020). The point is that, to solve current social and environmental problems (Hodson, 2003), we need a generation of scientifically literate citizens capable of identifying misinformation, developing inquiry-based habits, feeding curiosity about what happens in social dynamics, and being open-minded (Sharon & Baram-Tsabari, 2020). This, in no case, excludes the educational responsibility of also promoting the scientific literacy of the adult population (Falk, Dierking, Swanger, Staus, Back, Barriault, Catalao, Chambers, Chew, Dahl, Falla, Gorecki, Lau, Lloyd, Martin, Santer, Singer, Solli, Trepanier, Tyystjarvi, & Verheyden, 2016).

Citizen Science is a generic concept that defines the active involvement of the general public in scientific research (Phillips, Ballard, Lewenstein, & Bonney, 2019). Its work dynamics describes the altruistic collaboration of citizens, interested in the most varied aspects of science, around scientific projects (Bonney, Cooper, Dickinson, Kelling, Phillips, Rosenberg, & Shirk, 2009; Miralles, Dopico, Devlo-Delva, & Garcia-Vazquez, 2016; Dopico, Ardua, & Garcia-Vazquez, 2017). Citizen scientists are usually ordinary people with little or none scientific experience, expert amateurs, or retired professionals (Groom, Weatherdon, & Geijzendorffer, 2016). Their previous training does not matter as much as their motivation. In this sense, a good recruitment strategy contributes to create a stable group of motivated and committed citizen scientists (Lee, Crowston, Harandi, Østerlund, & Miller, 2018). Motivation, patience, and – let's be honest – some resistance to frustration will be necessary for Citizen Science programs. A research process takes a lot of time and effort to be carried out (Walliman, 2017). The results in science do not appear suddenly. Sometimes it takes a long time before having solid elements that provide evidence or that make a difference. Then, motivated citizens recruited by scientists, following scientific methods, not only collaborate in finding research results, but they also acquire scientific knowledge by developing the research process. As a practical training activity, Citizen Science could be a good resource to boost science literacy.

Mumby, Harborne, Raines and Ridley (1995) pointed out that, despite the lack of scientific training, most citizen scientists obtain satisfactory data sets. However, the

scientific community sometimes challenges the results of Citizen Science, for possible gaps in the accuracy, reliability, and validation of the data (Jiménez, Triguero, & John, 2019). If they rely on the mere collection of samples or data, Citizen Science projects may show some weakness in their contribution to science literacy (Mueller, Tippins, & Bryan, 2011). If citizen participation is limited to data collection (Lukyanenko, Parsons, & Wiersma, 2016), their scientific knowledge does not progress. Citizen Science projects are somewhat more. They become a collaborative work environment between scientists and citizens following a research process in which knowledge is generated and learning skills are implemented. Citizens acting like scientists (proceeding according to the experimental design, contrasting the apparent with the demonstrable...) have stronger positive attitudes toward science literacy. However, if a shared common space of interests and meanings between scientists and citizens is not established, citizens will not find their engagement meaningful or necessary in true research contexts, and their learning potential could be compromised.

In socio-educational environments, Citizen Science experiences obtain good results in terms of improving participants' science literacy (Ballard, Dixon, & Harris, 2017; Saunders, Roger, Geary, Meredith, Welbourne, Bako, & Kunstler, 2018). To citizen scientists, science literacy plays a key role because it enables volunteers to participate in one way or another in the whole research process, in a rich and fluent interchange of open views and opinions with the project researchers (Cooper, 2016). It seems that, when volunteers contribute with valuable information on biodiversity, their science literacy increases at the same time (Cohn, 2008). For Brossard, Lewenstein and Bonney (2005), disclosing information about scientific procedures promotes the scientific understanding of the general public. Even a short training period serves to improve science literacy and self-reported engagement in pro-environmental activities (Kvanvig, 2003; Crall, Jordan, Holfeder, Newman, Graham, & Wallar, 2013). Moreover, the volunteers can transfer the knowledge acquired during Citizen Science projects to other contexts (Jordan, Ehrenfeld, Gray, Brooks, Howe, & Hmelo-Silver, 2012).

The European Commission (EC) framed all intentional learning activities aimed at improving knowledge, skills, and competences within the concept of lifelong learning (EC, 2000). Lifelong learning programs for adults try to satisfy their educational needs by providing learning opportunities that meet their training needs. Although the correlation between age and a decreased motivation to learn has been identified (Marcaletti, Iñiguez Berrozpe, & Koutra, 2018), adults involved in lifelong learning (LL) programs are highly motivated for other activities (Merriam & Kee, 2014), and could be excellent candidates to develop Citizen Science experiences. In the last decades, *mid-lifers* have been increasingly involved in LL initiatives (Davey, 2002; Volles, 2016). Adults join lifelong learning programs because they want to keep on learning (Head, Van Hoeck, & Garson, 2015), and at the same time they receive other benefits, as LL brings along significant improvements to the participants' quality of life and wellbeing (Cooper, Field, Goswami, Jenkins, & Sahakhian, 2010; Field, 2012; Boeren, 2016). In this sense, we wanted to explore the possible advantages of crossing over LL and Citizen Science dynamics.

Understanding science learning as a tool to improve communities (Roth & Barton, 2004), that drives reasoning, critical thinking, and inquiry-based knowledge, the present study is part of a broader multidisciplinary research project in which the aim is to develop tools for the sustainable use of marine resources. The purpose in this part of that larger project was the formation of a Coastal Observation Network of citizens, where occasional help in laboratory tasks for marine species identification would be needed. We therefore wanted to know if LL – here, in the sense of Faure report, lifelong learning is understood

as personal development and fulfillment (Faure, Herrera, Kaddoura, Lopez, Petrovsky, Rahnema, & Ward, 1972) – could facilitate scientific literacy and the transfer of scientific knowledge to other contexts; and if it may serve as a platform for successful recruitment in Citizen Science initiatives. For this purpose, we created two groups of volunteers. In one of them, the participants were involved in the LL program of the University of Oviedo aimed at the general university education of people over 50 (<http://www.uniovi.es/en/estudios/pumuo>). In the other, the participants were from the general public, not involved in said program. Placing the educational focus on an adult population requires the understanding of how adults approach learning and how they find meaning in new knowledge. This way, we designed a didactic plan in which the main objective was placed on science literacy practices, adjusted to the profile of adult participants (Hippel & Tippelt, 2010; Tsai, Li, & Cheng, 2017). Consequently, we developed a methodology based on experiential learning (Morris, 2019), linked to their own experiences and focused on the environment (Lucio-Villegas, 2016). Thus, an initial short seminar about aquatic biodiversity was followed by a hands-on lab workshop based on Kolb's *here and now* model (Miettinen, 2000), that took advantage of what the participants had already learned about DNA-based species identification in the previous short seminar. That is, the learning experience provided by the previous seminar facilitates the acquisition of new knowledge. In the continuum of the theoretical contents offered in the seminar and the practical activities developed in the workshop, keeping the key concepts fresh could contribute to the success of experiential learning.

## Materials and methods

### *Sociological data and samples*

This experience was carried out in Asturias (Europe-Northwestern Spain). The call for participation was opened in six cities/villages of the region. Announcements, explaining the nature and purposes of the project to form a Coastal Observation Network of volunteers to develop a Citizen Science initiative, were published on media and regional fisher associations, diving clubs, and environmental agencies. The adults enrolled in LL programs of the University of Oviedo were directly invited to join the activity. The University of Oviedo offers two different lifelong learning programs in Asturias: one based on trimestral courses in different cities of the region, and one two-term (year-long) Program for Mature Students. Both programs publicized the call to this Lifelong Education initiative. The call was specifically addressed to persons without experience in molecular biology.

The first phase of the Citizen Science recruitment was a short open seminar about aquatic biodiversity. In the second phase, the participants were invited to attend a free 4-hour laboratory workshop in the University of Oviedo. They were informed about the workshop content: practical lab work on DNA and its use for distinguishing between similar species, which is very important in natural sciences. The names and contact emails of potential participants in the workshop were collected *in situ*. The participants were contacted via e-mail and assigned to one of the three workshop editions organized. In each edition, we gathered the same amount of lifelong learners and general public, trying to distribute the participants in three similar groups in terms of diversity of age, sex, and previous scientific knowledge.

### ***Short seminar/Concrete Experience***

The duration of the seminar was one hour. First, a short presentation supported by PowerPoint slides took place for approximately 15-20 minutes (*circa* one slide/minute). To make it easier for the participants to balance their experience and their understanding of the didactic contents, these were presented in a sequenced way: I) Introduction to the biodiversity, focused on aquatic ecosystems; II) Local fishing resources; III) Difficulties of distinguishing fish *de visu*; and IV) Use of DNA to identify the species in unclear cases. The examples were focused on fish because fishing is an important resource in the region, and because many new fish species that do not appear in nature guides are being introduced in Spain (e.g. Leunda, 2010).

### ***Laboratory workshop***

Taking into account the attributes of adult learning assigned by Knowles, Holton III, and Swanson (2015), the experiential learning (Kolb, Boyatzis, & Mainemelis, 2001) driven in the lab workshop of the second phase was based on active experimentation. It was organized in groups of a maximum of 14 participants, in the area of Genetics of the University of Oviedo, at no cost for the participants. In the first part (30 min), an introduction to basic concepts of molecular biology was taught. These were: I) Introduction to DNA, i.e. DNA structure, its location within a cell, its function in inheritance, and its unique sequences that can identify a species and distinguish it from the rest of species; II) Introduction to DNA manipulation, i.e. the rationale for DNA extraction (breaking cells, precipitating DNA in ethanol), and separation of DNA molecules by gel electrophoresis (DNA molecules migrate to the positive pole at different speed depending on their size); III) Introduction to PCR (multiplication of DNA copies by polymerase chain reaction); and IV) Basic safety rules in a laboratory of molecular biology, i.e. equipment and chemicals employed, protection and sterility measures.

Laboratory coats and gloves were worn at all times within the lab. In the first hands-on minutes, the participants explored freely a set of pipettes, tubes, Petri plates, and small materials required for DNA extraction. Only harmless non-toxic products were used for DNA extraction. For the sake of simplicity and to make molecular procedures more familiar to first-time laboratory users, we employed a protocol based on common domestic products: salt, kitchen detergent, and ethanol (Britos, Goyenola, & Oroño, 2004). DNA was extracted from different species of well-known fish in the region: whiting, sardines, brown trout, and rainbow trout. It took approximately 30 minutes.

After DNA extraction, a 1% agarose gel was prepared, adding SimplySafe™ (EURx) for non-toxic DNA staining. DNA aliquots were loaded on the gel by each participant, using micropipettes, and were run by electrophoresis at 100V for 20 minutes. Then, DNA was visualized on the gel in a UV chamber with adequate safety measures. Photographs of the gel were taken, and copies were printed out for the participants. At the end, there was a short computer session dedicated to see chromatograms representing real DNA sequences of a species-specific gene (cytochrome oxidase I, COI), downloading the sequences in FASTA format, and uploading them in a public database (Barcoding of Life Diversity, BOLD ([http://www.boldsystems.org/index.php/IDS\\_OpenIdEngine](http://www.boldsystems.org/index.php/IDS_OpenIdEngine)) to retrieve the closest match reference sequence of a known species. This last part (online matching a DNA sequence from an unknown species with a reference sequence of a known species) is the basis of the species determination based on DNA.

Table 1. Schedule of the laboratory workshop, and educational levels where these contents (or equivalent theory and practice) are taught in formal education in Europe.

Section	Contents	Level	Time
<b>Introduction to the DNA</b>	Explanation with visual support about the location, structure, function and basic properties of DNA, representation of sequences in chromatograms and FASTA format.	<i>Secondary education to undergraduate</i>	20 min
<b>Laboratory safety</b>	Safety measures for working in a molecular lab.	<i>Secondary education</i>	10 min
<b>Handling of lab material</b>	Practical use of pipettes, centrifuge, tubes, vortex.	<i>Secondary education</i>	20 min
<b>DNA extraction</b>	DNA extraction from fish using a protocol based on common products: salt, bicarbonate, ethanol and water. Explanation of the process (dissolving cell membranes, chemical affinity of DNA).	<i>Primary to secondary education</i>	30 min
<b>Electrophoresis</b>	Loading an agarose gel with DNA extracted by the participants.	<i>Secondary education</i>	20 min
	Setting the voltage and running the gel; explaining again the principles of electrophoresis.	<i>Secondary education</i>	20 min
	Stopping the electrophoresis and removing the gel from the cuvette.	<i>Secondary education</i>	5 min
<b>DNA visualization</b>	DNA visualization on the gel under UV light with proper safety measures; taking and printing pictures of the gel.	<i>Secondary education</i>	10 min
<b>DNA for species identification</b>	Uploading COI sequences on the BOLD database and checking the species.	<i>Undergraduate</i>	30 min

The teaching contents of the DNA workshop were based on the common contents of the European science curriculum at the different educational levels. (Forsthuber, Motiejunaite, & de Almeida Coutinho, 2011).

### *Post-workshop questionnaire*

Learning rarely occurs immediately. It requires time, reflection and integration in previous knowledge (Kostiainen, Ukskoski, Ruohotie-Lyhty, Kauppinen, Kainulainen, & Mäkinen, 2018). The most consistent teaching practice points out that meaningful learning cannot be produced without meaningful teaching. So, to measure what was learned from the experience and to get references about the effects of the teaching process in the participants' construction of knowledge, they were passed an online questionnaire two weeks after the workshop.

Table 2. Questionnaire used in this study with the specific and general topics treated in each group of questions.

Item	Specific topic	General topic
After the workshop I know better where DNA is located in cells and tissues	<i>DNA location</i>	<i>DNA properties</i>
In the workshop I have learned about the main DNA features	<i>DNA structure</i>	
I understand now how to use DNA for species identification	<i>DNA specificity</i>	
I have learned here how to use a pipette	<i>Equipment</i>	<i>DNA manipulation</i>
I know how electrophoresis works and what it serves for	<i>Process</i>	
I know security measures that are necessary in molecular labs	<i>Laboratory security</i>	
I have learned many new things in this activity	<i>Formative value</i>	<i>Workshop evaluation</i>
I have enjoyed the workshop	<i>Enjoyment</i>	
I understood what was explained in the workshop	<i>Understanding achievement</i>	
I will recommend this workshop to my friends	<i>Recommendable activity</i>	
I intend to enroll again for other similar activities	<i>Learning motivation</i>	<i>Engagement</i>
I intend to volunteer for the Coastal Observation Network to be launched within one year from now	<i>Recruitment</i>	

The items were organized in four groups to measure the perceived learning gains, attitudes towards the workshop, and motivation to continue learning or to keep engaged. For the perceived learning gains, we asked about their self-perception of achievement, i.e. how much they felt they had learned about the properties of DNA (three questions) and laboratory procedures (three questions). With regard to attitudes, what interested us was to know the behavioral variability on the proposed tasks and, therefore, we asked about their overall assessment of the workshop (four questions). Finally, the motivation through self-reported intention to engage in other activities (two questions) could also offer us information on whether this educational experience had met their expectations/needs. The questionnaire was organized as a rating scale (1, lowest score; 5, highest score, for least to most agreement).

The principles of anonymity and ethical rules for social studies (Ferreira & Serpa, 2018), and the normative approved by the Committee of Ethics of the University of Oviedo were followed. The participants provided, together with the answers, the following information: sex, age, group (lifelong learners or general public), occupation, and educational level as the highest diploma obtained (Primary, Secondary, Higher education).

### *Statistical analysis*

Two-factor ANOVA was employed for the comparison of the perceived learning gains and attitudes to keep learning among groups. Factor **A** was the enrollment in Lifelong Learning programs (*Yes* versus *No*), and Factor **B** was the occupation as a proxy for general availability (from least to most expected free time: *Employed*, *Unemployed* and *Retirees*). A posteriori pairwise comparisons were carried out with Student-t tests, and variance equality was checked with F-tests. A comparison between groups for other characteristics such as sex composition and educational level was done with contingency Chi-Square tests, with Yates correction whenever necessary. For correlations, we

employed parametric Pearson's  $r$  after checking the required conditions (sample size, data normality). The software PAST3 version 3.01 (Hammer, Harper, & Ryan, 2001) was employed for statistical analysis.

## Results

In total, 277 persons attended the seminars: 157 of the group of general public and 120 lifelong learners. Although everyone was interested in scientific matters, 41 of them freely applied to participate in the laboratory workshop. A successful teaching dynamic requires a smooth collaboration and interaction between teachers and students (Merriam & Baumgartner, 2020). So, to trigger an adequate teaching-learning process we adjusted the teacher/students ratio.

### *Participants results*

The recruitment for the second phase (workshop) was 18 persons from the first group (11.5%) and 23 (19.2%) from the second one (lifelong learners). Since the proportion of the groups in the final sample is equivalent to the proportion of the groups in the original sample, the difference between the two groups for the second-phase recruitment was not statistically significant (Chi-square=3.219, 1 degree of freedom,  $P>0.05$ ). A global 14.8% of the participants in the first phase participated also in the second phase.

Table 3. Characteristics of the participants in this study.

<b>Participants</b>	<b>Lifelong learners</b>			<b>Non-lifelong learners</b>		
<b>Average age</b>	57.1 (SD 11.9)			47.6 (SD 14.6)		
<b>Gender</b>	<i>Females</i>	<i>Males</i>		<i>Females</i>	<i>Males</i>	
	69.5%	30.5%		44.4%	55.6%	
<b>Educational qualifications</b>	<i>Primary Education</i>	<i>Secondary Education</i>	<i>Higher Education</i>	<i>Primary Education</i>	<i>Secondary Education</i>	<i>Higher Education</i>
	23%	36%	41%	11%	39%	50%
<b>Socio-economic status</b>	<i>Retirees</i>	<i>Unemployed</i>	<i>Employed</i>	<i>Retirees</i>	<i>Unemployed</i>	<i>Employed</i>
	26%	26%	48%	11%	33%	56%

Considering the participants that completed the two phases of the activity [Table 3 near here], lifelong and non-lifelong learners were not significantly different in sex ratio and level of studies (Chi-square of 2.627 and 0.487 respectively for 1 and 2 degrees of freedom, both not significant), with 44.4% females and 50% graduates in non-lifelong learners (general public) versus 69.5% females and 41% graduates for lifelong learners respectively.

The two groups were however significantly different in age, lifelong learners being older (57.1 versus 47.6 mean age with standard deviations of 11.9 and 14.6 respectively,  $P=0.040$  for a two-tailed t-test for samples with different variance). Regarding the occupational status (indicator of availability), a significant difference was logically found among the groups with a higher proportion of retirees in the lifelong learning group ( $P=0.0007$ ), because, generally, retirees have more free time to engage in diverse activities. The mean age of employed and unemployed participants (excluding retirees from the analysis) was not significantly different between lifelong and non-lifelong learners ( $F=3.686$  in a two-way ANOVA, not significant).

### Perceived learning gains

Regarding the perceived knowledge acquired during the DNA workshop, lifelong learners understood less than non-lifelong learners the use of DNA for species identification (P-value=0.04), as well as the process of electrophoresis (P=0.004).

Table 4. Left: Mean age and score of each item of the questionnaire (SD in parenthesis), per group of participants classed by lifelong learning and occupation status. Right: F-values for each factor and their interaction in two-way analysis of variance. Significant p-values <0.05, <0.01 and <0.001 as one, two and three asterisks respectively.

		Mean scores						Two-way ANOVA F-values		
		Lifelong learners			Non-lifelong learners			Lifelong learning	Occupation	Interaction
		Retirees	Unemployed	Employed	Retirees	Unemployed	Employed			
	<i>Age</i>	66.2 (0.8)	49.5 (19.7)	57.2 (6.0)	68 (2.8)	38.8 (16.7)	48.5 (10.7)	7.557 **	8.921***	0.96
<b>DNA characteristics</b>	<i>Location</i>	4.33 (0.82)	4 (0.89)	4.55 (0.82)	5 (0)	4.5 (0.84)	4.5 (1.27)	0.476	0.332	0.504
	<i>Structure</i>	3.5 (1.05)	3.7 (0.82)	4.64 (0.67)	4.5 (0.7)	4.8 (0.41)	4.4 (0.7)	4.06	3.205	4.182*
	<i>Specificity</i>	3.2 (0.75)	3.3 (0.82)	3 (1.26)	3.5 (0.7)	4 (0.89)	3.8 (1.23)	4.336*	0.425	0.189
<b>DNA manipulation</b>	<i>Equipment</i>	4.3 (0.82)	4.2 (0.75)	4.8 (0.6)	5 (0)	4.8 (0.41)	4.4 (0.7)	0.188	0.169	3.319
	<i>Process</i>	2.5 (0.84)	3.2 (0.98)	3.1 (0.94)	3.5 (0.7)	3.8 (0.75)	3.8 (0.79)	9.106**	2.163	0.286
	<i>Lab security</i>	4.2 (0.98)	4.3 (0.82)	4.1 (0.94)	4.5 (0.7)	4 (1.26)	4.3 (1.16)	0.022	0.016	0.323
<b>Workshop evaluation</b>	<i>Formative</i>	5 (0)	5 (0)	5 (0)	5 (0)	4.8 (0.41)	4.8 (0.42)	4.034	0.391	0.413
	<i>Enjoyable</i>	5 (0)	5 (0)	5 (0)	5 (0)	4.8 (0.41)	4.9 (0.32)	2.517	0.332	0.332
	<i>Understandable</i>	4.7 (0.82)	4.7 (0.81)	4.9 (0.3)	5 (0)	5 (0)	4.8 (0.42)	0.435	0.127	0.914
	<i>Recommendable</i>	5 (0)	5 (0)	5 (0)	5 (0)	5 (0)	5 (0)	-	-	-
<b>Post-workshop attitude</b>	<i>More activities</i>	4.8 (0.41)	5 (0)	5 (0)	5 (0)	5 (0)	5 (0)	0.802	2.113	0.819
	<i>Engagement</i>	4.8 (0.41)	4.8 (0.41)	4.9 (0.3)	4.5 (0.7)	4.7 (0.52)	4.1 (1.2)	5.871**	0.529	0.975

Significant differences regarding occupational status did not appear for any item of the questionnaire. Significant interaction between lifelong learning motivation and occupational status was obtained for the understanding of DNA structure.

The possible effect of age on the understanding of molecular biology was checked by Pearson correlation  $r$  tests between age and the questions related with molecular biology.

Negative  $r$ -values were found for the two items that provided significant  $F$ -values in the ANOVA, Process (electrophoresis) and Species (use of DNA for species identification):  $r = -0.364$  and  $-0.463$ , with  $p < 0.05$  and  $0.01$  respectively. This indicates that older participants found more difficult to understand these concepts than younger participants. Other significant  $r$ -values between age and questionnaire items were not found.

### *Attitudes and motivation*

For the global evaluation of the workshop, the factors considered did not contribute significantly to the ANOVA in any case. On a scale 1-5, with 5 being the highest score, the workshop was judged formative, enjoyable, understandable, and recommendable, with scores close to 5 in all cases.

The groups of participants did not differ in their intention to participate in further activities of science education. Significant differences between lifelong and non-lifelong learners were found, however, for engagement in the Network of Coastal Observation (item “Engagement”,  $P = 0.021$ ) because lifelong learners self-reported more intention to engage. No significant correlation with age was found for this item ( $r = 0.296$ , not significant). If retirees are excluded from the analysis, the ANOVA is still significant for lifelong learning status ( $F = 4.859$  with  $P = 0.03$ ). Self-reported engagement scores for lifelong and non-lifelong learners (all ages and occupational groups included) were 4.33 and 4.87 respectively, significantly different in a two-tailed test ( $t = 2.237$ ,  $P = 0.036$ .)

When the participants were asked to enroll in the Network of Coastal Surveillance, all except one (40/41, 97.5%) accepted engaging in the Citizen Science action. This number corresponds to 14.4% of the 277 participants in Phase-1. The engagement of Spanish citizens in volunteering ranges 0.4-5.0% and is 2.5% in environmental activities (5.8% if past and sporadic activities are considered). A 14.4% is more than double of the percentage of Spaniards engaged any time in environmental actions. The difference is indeed statistically significant ( $P = 4.04 \times 10^{-5}$  in a  $z$ -test).

### **Discussion**

The promotion of citizen scientific literacy is the main pedagogical purpose of this study. On the methodological framework of experiential learning, and considering both the characteristics of the participants and those of the learning process itself (Yin & Lim, 2020), a short experiential learning seminar followed by a hands-on workshop was designed for adults. The results obtained regarding the participants’ perceived learning gains, their attitudes towards this educational experience, and their motivation to continue involved in similar dynamics, suggest that mature lifelong learners are more motivated to engage in activities of science education than non-lifelong learners. Although based on limited sample size, robust statistical significance supports the idea that lifelong learning groups could be a very good target group to recruit as citizen scientists. Higher motivation for engaging was self-reported by lifelong learners, in spite of the fact that their science

understanding was not better than that of the general public – rather the opposite –, as can be deduced from their lower scores in the items about DNA characteristics and manipulation. The cause of the lifelong learners' less perceived learning gains could be their age (Glendenning & Stuart-Hamilton, 2017) or their greater ability to cope with uncertainty (Nassar, Bruckner, Gold, Li, Heekeren, & Eppinger, 2016). It is also possible that they measure their expectations of achievement with greater self-criticism derived from their role as LL students. Lifelong learners in our sample were older than non-lifelong learners, and, although older lifelong learners learn better with practical tasks (Simone & Sculli, 2006), in our research, age was negatively correlated with the perceived understanding of molecular processes and DNA uses. This could be explained by the changes in science education programs occurred in Europe during the last decades. Currently, science is taught through a meaningful combination of lectures and lab practices (Vazquez, 2006; Karakasi, 2018). Although a poor genetic literacy has been revealed (Chapman, Likhanov, Selita, Zakharov, Smith-Woolley, & Kovas, 2019), molecular biology and DNA are included in all curricula in secondary education for the younger European generations. (e.g. Martinez-Gracia, Gil-Quilez, & Osada 2006; Leaton Gray, Scott, & Mehisto, 2018). Thus, learning about DNA uses and analytical processes was probably easier for the younger participants than for the older ones. In this sense, future research to analyze the study programs aimed at adults would be appropriate.

Learning does not happen instantly. Understood as a purpose-oriented mental process, it requires conscious reflection (Dantas & Cunha, 2020). Here, the learning gains of the participants in the workshops were evaluated from a questionnaire after their experience in labs. For Crall et al., (2013), survey instruments should be calibrated to a series of factors such as the pre-existing attitudes, behavior, and levels of knowledge; hence the need to thoroughly reflect at the design of the items in the questionnaire, as the questions asked may or may not reveal adequate information for the investigation. Since our work is about an educational intervention, it is also important to measure the learning experience (Barry & Egan, 2018). The sample of our study has certain limitations, but still, our results suggest that age should be added to this list of factors, since it may affect the understanding of science at least in some topics (molecular biology could be one of them), likely as a consequence of the previous level of knowledge. However, despite their lower understanding of science, older participants were not discouraged to keep involved in this informal context of hands-on experiential learning. On the contrary, as in other studies (Manninen & Meriläinen, 2014; Retzbach, Otto, & Maier, 2015; Jones, Corin, Andre, Childers, & Stevens, 2017; Bjursell, 2019), they showed a greater motivation to learn and greater social interaction initiatives with the group. Boosting research on learning in adulthood (Schmidt-Hertha, Formosa & Fragoso, 2019), in an increasingly aging Europe, is a stimulus and a challenge for pedagogy aimed at adults.

Volunteering is an expression of citizenship for the elderly (Lie, Baines, & Wheelock, 2009), and one could wonder if the self-reported intention to engage in future environmental surveillance is associated with age. This has not been found in our study ( $r = 0.29$  with 40 degrees of freedom, not significant). It seems that it is not the age *per se*; but instead lifelong learning what really motivates participants to undertake other activities, in this case Citizen Science for environmental monitoring. When we talk about the scientific literacy of the citizenship, there are some doubts about the long-term impact that science communication activities can have on inexpert public (Bucchi, 2013), but we think that the two-phase pre-recruitment activity here conducted could be considered motivational for environmental and science education. The intention to enroll in similar workshops on molecular biology was almost 5 over 5 in all cases. In Phase-1, participants were informed about the importance of DNA to identify species, so they had a view of

potential applications of DNA science in the real world, which is a great motivation for science learning (Braund & Reiss, 2006; Taconis & den Brok, 2016), and a clear reflection of the transfer of learning beyond these teaching-learning events (Roumell, 2019). It seems that the ecological message has engaged the audience, which is one of the challenges for scientists to communicate with society (Groffman, Stylinski, Nisbet, Duarte, Jordan, Burgin, Previtali, & Coloso, 2010).

In Spain, the active participation of citizens in volunteering is unfortunately weak (Spanish Ministry of the Presidency, 2015). However, and saving the proportions between the whole population of the country and the number of participants in this adult education experience, our results also show a much higher engagement of participants involved in this two-phase recruitment activity than the average for Spain (14% versus 5.8%). This suggests that including an experiential hands-on scientific practice in the recruitment process does not only act in boosting scientific literacy, but it may also be a motivation to participate in the process of a science research. We have tried to show how ordinary citizens can participate in scientific processes and at the same time increase their science literacy, or at least their curiosity for science. This seems to serve to enhance Citizen Science recruits as well. We are enthusiastic supporters of lifelong educational initiatives like these workshops we develop, that try to promote science literacy for everyone everywhere. The teachers are committed to knowledge and must choose and propose the best methods (Malach, 2020) to facilitate it. So, we need to open the doors of the Faculties and laboratories to the citizens, not just the students who pay their registration fees.

An essential objective in this socio-educational initiative was to design a didactic planning directed to the common people in Dewey's experiential learning way (1938). This involved: providing scientific literacy by participating in scientific learning activities; overcoming the recruitment of volunteers as simple collectors of samples and data in research; and opening spaces where they also could contribute to data analysis and into the science outreach. We think that the direct contact of researchers with citizen scientists involves not only a motivation towards learning, but also the active involvement of citizens in all research processes. In the near future, a wider participation of formed and informed citizens in environmental issues will be a priority in conservation sciences. That's why we would suggest coordinating Citizen Science and Lifelong Learning programs, because both can benefit a lot from mutual interaction.

## **Acknowledgments**

We are grateful to the Federation of Subaquatic Activities of Asturias, regional fishermen associations, the Evolution Club of the University of Oviedo, and many volunteers that kindly contributed to this initiative. Special thanks to Aida D. G. for language edition.

## **Funding**

This study was funded by the Spanish projects MINECO CGL-2016-79209-R, FCT-13-6105 and GRUPIN IDI-2018-201. This is a contribution from the Marine Observatory of Asturias (Spain).

## Ethical statement

The normative framework followed as ethical code of good practices in this research, where there are human beings involved, is based on the recommendations made by intergovernmental institutions such as the Council of Europe, UNESCO, or the European Science Foundation (ESF). The research ethics committee of the Principality of Asturias has reviewed, evaluated, and approved the research project with the reference number 99/16.

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