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Title: *Find invasive seaweed*: an outdoor game to engage children in science activities that detect marine biological invasion.

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Abstract:

Invasive species threaten worldwide biodiversity. Success in facing this problem may be possible through the engagement of younger audiences. Here, a game was designed to teach children how to recognize invasive seaweed and to encourage them to participate in marine citizen science. The game was first tested in a pilot study, and then carried out in Salinas High School (Asturias, Spain). Game-based training consisted of an explanation of invasive species, followed by the '*Find invasive seaweed'* game and was evaluated with tests before and after the activity. After training, students spent 3 months looking for invasive species. Four invasive species were detected in the study area. The results showed a positive impact on knowledge gains and significant differences in marine environmental awareness and conservation actions.

Keywords: Citizen science, game, engagement, invasive seaweeds, children, algae

Introduction:

Nonindigenous species (NIS) and, particularly, invasive alien species (IAS) pose a serious threat to biodiversity in marine ecosystems (e.g., Chown et al., 2015) in most biogeographical regions (Thomsen et al., 2016). Marine biological invasions require complex management involving researchers, managers and citizens for successful control and biosecurity (e.g., Hershdorfer et al., 2007, Larson et al., 2011). Thus, it is of key importance that citizens be informed about new knowledge and management of IAS, as well as advances in scientific contributions (Silvertown, 2009). Among other approaches, citizen science can be a participatory strategy that connects the general public with scientific advances.

Citizen science:

Citizen science (CS) is a participatory strategy in which citizens and scientists work together in research projects (e.g., Irwin, 1995; Bonney et al., 2014). Recently, the number of CS projects has expanded exponentially (McKinly et al., 2016; Pocock et al., 2017), primarily focusing on biology, the environment and ecology (Kullenberg & Kasparowski, 2016). However, marine CS is fragmented, relative to wider spatial and long-term integration of terrestrial initiatives (Theobald et al., 2015; Garcia-Soto et al., 2017; Science Europe, 2018). Logistic obstacles, safety and the fact that most of the humans spend a minor part of their life on the water could be some of the reasons why the marine environment poses a challenge for engaging the general public (Cigliano et al., 2015). Once engaged, marine CS can serve as a valuable platform to connect citizens to ocean environments and to support ocean protection or conservation management (Kelly et al., 2019). Thus, the need to comprehend how to engage the public in CS projects related to marine conservation is necessary (Vincent, 2011; Fletcher et al., 2012; Ballard et al., 2017; Dean et al., 2018) and desirable. An example of successful engagement is the enrolment of school children and scientists in a large-scale sampling of marine litter along the coast of Chile, where 96% of participant students stated that they would like to participate in future CS activities (Eastman et al., 2014).

Educational games:

Games are a powerful tool for learning and can engage participants in difficult tasks (Hoffman & Nadelson, 2009). In CS projects, games appear to motivate and encourage participation (e.g., Iacobides et al., 2013) and to engage and foster a spirit of conservation in children (Davis 1998, Davis & Elliot, 2003; Hartley et al., 2015).

The efficacy of gaming as an intervention in education can be extrapolated from the growing number of papers published (e.g., Hamari et al., 2014). Educational games help students develop a better understanding of the teaching-learning process in which they are involved (Franco-Mariscal et al., 2015; Huizenga et al., 2017; Martí-Centelles & Rubio-Magnieto, 2014). Participants develop new cognitive and operational abilities by teaching and learning specific subjects, and new possibilities emerge with regard to obtaining an improved understanding and reinforcing complex concepts that are difficult to comprehend (Al-Azawi et al., 2016; Miralles et al., 2013).

Under the hypothesis that games could help fostering CS and at the same time educate about IAS and marine conservation, an original educational game was created for children in formal education but is accessible to people of all ages and contexts. It was developed to: *i*) teach citizens to identify invasive seaweeds based on taxonomic phenotypic characteristics and *ii*) motivate and encourage the general public, particularly younger generations, to participate in marine citizen science activities. The game was first tested in a pilot study and was ultimately included in a CS project with high school students. Levels of recruitment, number and type of NIS/IAS seaweed species detected by children within the area, and pre- and posttests were used to evaluate the game with regard to its learning and motivation efficacy.

Materials and methods:

Game materials:

- 'Marine invasive seaweed cards' (Figure 1) containing information about invasive seaweed along the Cantabrian Sea (Northeast Atlantic). Cards can be modified for any other marine region to include the IAS therein. Cards had a picture of a real specimen, with its scientific name on the front of the card and a short description of its impacts on the reverse. Based on Cires and Moliner (2010) and Peteiro (2014), the game included the following species:

   - *Codium fragile* subsp. *fragile* (Suringar) Hariot 1889 (Scheibling & Gagnon, 2006)
   - *Undaria pinnatifida* (Harvey) Suringar 1873 (Casas et al., 2004),
   - *Sargassum muticum* (Yendo) Fesholt 1955 (Britton-Simmons, 2004),
   - *Grateloupia imbricata* Holmes 1896 (Ramalhosa et al., 2016; Montes et al., 2016),
   - *Asparagopsis armata* Harvey 1855,
   - *Colpomenia sinuosa* var. *peregrine* Sauvageau 1927 (Cotton, 1908)
   - *Polysiphonia schneideri* B. Stuercke & D. W. Freshwater 2010.
- Invasive specimens preserved as herbarium material from the University of Oviedo (https://www.unioviedo.es/bos/Herbario/FCO.htm) (Figure 2, Item A).
- Fresh samples of marine invasive seaweeds preserved in absolute ethanol (Figure 2, Item B).

Game action:

Before starting the game, a secure place (e.g., a playground or fenced area) must be found where samples of items A and B can be hidden. Additionally, a game leader (the person in charge of the game) should supervise the activity. Based on the number of participants, small working teams can be formed to stimulate participants to reach the common goal: to collect and identify as many hidden items as possible. However, the game may also be played individually, as some participants may have limitations that preclude them from engaging in group play mode (Iacovides et al., 2013).

The game starts when all items (A and B type) are concealed in the selected area. Then, cards for each species are given to the participants with a brief explanation about each species. Independent searching is not allowed in the case of team play and all participants start the game at the same time.

When the participants find one item (A or B type), they have to compare it with the 'Marine invasive seaweed cards' to correctly identify the target seaweed. If identification is correct, the game leader asks them a question about the species. Interaction between team members to answer the question correctly increases team efficiency (Rania et al., 2015). If the team correctly identifies the seaweed species and answers the question, they get one point and can proceed with the game. If the identification is incomplete or the question is answered incorrectly, they must continue the game by looking for other hidden items. The game concludes when all the items have been found. If the time allotted for the activity ends and/or participants cannot find all the items, the team with more points wins. The points system can help establish a ranking. Competition in a game can be an important element that contributes to engagement, motivation to learn, and cognitive learning outcomes (Ruggiero, 2013; Huizenga et al. 2017).

Ethics statement:

This study adheres to the European Code of Conduct for Research Integrity. Informed consent was obtained from all participants to use the collected data for research publication. This scientific game was specifically designed and developed for educational purposes, to implement training and to recruit volunteer for CS. The game has been registered in Spain (copyright IP 05/2017/358).

To avoid the unlikely possibility of collecting any living specimens or any possibility of NIS dispersion, all participants were made awared of biosecurity guidelines, such as not taking algae from other beaches, not transferring algae between beaches, keeping all fragments under supervision until they were stored in ethanol, checking shoes for small seaweed fragments before leaving the beach, etc. Specifically, on the beach, only detached specimens found lying on the sand were collected. All collected samples were immediately stored in absolute ethanol and transported to the Department of Organisms and Systems Biology at the University of Oviedo.

Initial pilot study:

The game was tested in a pilot study to avoid potential obstacles and identify possible constraints in order to achieve the objectives and clarify doubts (Hassan et al., 2016). The first game trial was completed during the *'Aula del Mar'* marine environmental education project in Salinas (North of Spain). Before playing, a short explanation was provided in which children were familiarized with invasive seaweed in Asturias..

Since *'Aula del Mar'* was 4 days in duration and it was located only 10 meters from the beach, we suggested to children to bring any detached fragments of possibly invasive seaweed that they could find lying on the beach to be identified *in situ*, as an approach to a possible CS project. *A*ll seaweed specimens were monitored and preserved in absolute ethanol to avoid any possibility of dispersion. Later, scientific identification was done at the University of Oviedo.

The case study:

The *'Find invasive seaweed'* game was assessed among children aged 11-12 (according to Spanish Educational Law, it is grade 1 of Educación Secundaria Obligatoria (ESO); grade KS4 in the UK and grade 8 in the USA) at Salinas High School (North Spain), which is located in front of one of the longest beach es in Asturias (approx. length: 2600m.). This study took place from April to June 2017.

Before starting, all seaweed (items A and B) was hidden inside of a fenced playground. The total time for game-based training lasted approximately 50 minutes and took place during one biology class. First, a ten-minutes pretest was completed before the game; the same test was given at the end of the game, as a posttest. After the pretest, a short but consistent introduction on the origin of seaweed invasion, the vectors of their introduction and ecological and economic impacts were explained, paying special attention to seaweed invading Asturias. Explanations were accompanied by pictures, examples and preserved samples. not focusing on the provision of information alone, but to highlight their impacts as suggested by previous marine CS projects (Dean et al., 2018). The game began on the playground, and students worked in teams to look for items A and B. After finishing the game, everyone came back into the classroom, and the posttest was given.

Finally, a modest marine CS project for monitoring IAS was carried out with the students. Glass containers with absolute ethanol were placed in the biology class for 3 months. All participants were encouraged to bring in detached fragments of potentially invasive seaweed. From April to June 2017, students went to the beach on weekends and brought seaweed fragments into class on Mondays..

Training and questionnaire:

To assess previous knowledge about invasive algae, a pretest was administered before the training, and a posttest was also completed immediately after the game to evaluate the success of the training and acquired knowledge.

A five-item test was designed in accordance with the objectives of the game to obtain clear responses to simply structured questions (Supplementary Materials Table S1). The first three items of the test assessed current knowledge of seaweed that was included in their school curricula: (Q1): the meaning of invasive species; (Q2): where seaweed live; and (Q3): how seaweed feed. All answers were scored as a 0 (I do not know), 1 (incorrect answer) or 2 (correct answer). Self-reported awareness of invasion issues was evaluated with the last two ítems: (Q4): awareness of consequences and effects of IAS; and (Q5): management actions when invasive seaweed is foundThese were scored using a Likert scale; ranging from 1 to 4, with 1 being the lowest level and 4 the maximum level of awareness.

An initial trial of the test was administered to 30 children and adults who were not involved in the study to check for inconsistencies and to confirm the understandability of the questions. For each of the items, the correlation between the item and the completed test, once the score of the former was removed from the score of the latter, was assessed using the Corrected Index of homogeneity (IHC; Peters and Van Vorhis, 1940). Only questions showing IHC>0.20 were used in the final questionnaire.

Differences between ‘correct,’ ‘incorrect’ and ‘don’t know’ answers (acquired knowledge: Q1-Q3) were evaluated using the Pearson chi-square test and comparisons of column proportions were evaluated using Bonferroni corrections (IBM SPSS Statistics 24). Evaluations of Q4 (awareness) and Q5 (management actions) before (pretest) and after (posttest) the game included comparisons in terms of means and distributions, using Levene's test to check for homogeneity of variance and the paired nonparametric Wilcoxon Signed-Ranks test (IBM SPSS statistics 24).

Results:

Initial pilot study:

Twelve children between 8 and 16 years old participated in the pilot game activity. However, in the following days more children (n=18, the original 12 participants in the training plus additional 6 children) brought in specimens of detached seaweed for scientific evaluation. The initial 12 children told their friends to help them, so more children than had initially participated in the game helped to collect detached seaweed. Thus, engagement in data collection and participation in this marine citizen science approach was surprisingly high, although the sample was small. This pilot group helped to develop dynamic and useful guidelines for the subsequent CS activity. Seaweed collection was successful and species were mostly exotic and invasive: *Grateloupia imbricata*, *Colpomenia sinuosa* and *Codium fragile* subsp. *fragile*

Citizen science case study:

In the final case study, 46 high school children (ages 11-12) participated in the game-based training and marine CS project from two different groups (1ºESO-A and 1ºESO-B). Test results were similar across the different classes suggesting that any class bias could be dismissed and that data could be pooled for statistical analyses. Answers in response to questions concerning knowledge gained from the curricula (items Q1, Q2 and Q3) revealed an increase in correct answers and a decrease in incorrect and 'don't know' answers after the game-based training (Figure 3). Global significant differences were found between pre- and posttests (Chi-square=15.167; p=0.001) and for each of the answers (p-value (correct)= 0.001; p-value (mistakes)= 0.031; p-value (don't know)= 0.003; Figure 3). Individually, significant differences were found for item Q1, relating to the definition of invasive species, between pre- and posttest - (P_{Q1}=0.0187), and also in items about the relevance and impact of invasive seaweeds Q4 (consciousness; P_{Q4}=2.66E-06) and Q5 about management actions (P_{Q5}=6.345E-11).

Participants' reported awareness was also positively increased after training (Figure 4). Significant differences before and after the activity were found for awareness (Z_{Q4}= -4.018, p-value=0.0001) and management (Z_{Q5}= -5.056, p-value=0.0001) (Figure 4). Only 52% of participants noted that it is highly important to conserve marine ecosystems for the environment, economy and society on the pretest, but this increased to 89.13% on the posttest (Supplementary Materials Figure S1). Evaluation of Q5 showed that although at the pretest just 36.9% of the participants knew how to proceed upon finding invasive seaweed, this number increased to 91.3% after the game (Supplementary Materials Figure S2). Children were able to recognize effective individual conservation actions as a result of the game.

Two groups collected algae samples from Salinas beach during the project. No differences were found with regard to the abundance of collected fragments. However, the number of participants in one group was highly different from the other (12 students out of 23 in one group and just 2 out of 23 in the other). Although they should have only collected invasive species, one native species, *Fucus vesiculosus* L. (Gallardo et al., 2016), was identified in one group container. The proportion of native fragments was very low (less than 10% of the total). Moreover, this marine CS project made it possible to detect another invasive species in the area: *Asparagopsis armata*.

Discussion:

CS activities targeting children as the primary participants in marine environmental surveys are scarce. In this project, we developed and evaluated an educational game about invasive seaweed to ultimately include it in a marine CS project. Using '*Find invasive seaweed*' game-based training, young local citizens were enrolled in a modest but valuable CS project that detected four different invasive species around Salinas beach in 2016-2017: *Asparagopsis armata*, *Grateloupia imbricata*, *Colpomenia sinuosa* and *Codium fragile* ssp. *fragile*. This was the first report of these four species in the area (Salinas, Asturias, North Spain). The detection of some species of the genus *Asparagopsis* could easily lead to misidentification of *A. armata* (Zanolla et al., 2014). The fact that some specimens of *A. armata* could be found by students and identified by researchers during the project emphasizes how valuable this activity could be for the scientific community. Hence, the '*Find invasive seaweed*' game, when linked to a CS project, could become an effective method for creating a powerful and beneficial exchange of data between scientists and junior citizens Volunteering with experts (e.g., scientists) at an early age increases motivation toward active participation in CS projects later in life (Morrow, 2003), increasing participants' scientific knowledge and developing positive attitudes toward science (e.g., Eastman et al., 2014; Crall et al., 2013). For all that, the game and the methodology presented here could be an easy tool to use in schools as a curriculum-based activity to engage children in marine conservation activities. The game-based training was focused on raising environmental awareness about the negative impacts of IAS, as they are recognized as a menace for ecosystem functioning (Elmqvist et al., 2003). Here, we surveyed self-reported awareness of invasive species among high school students, and the results revealed a significant increase after the game-based training that could positively contribute to achieving conservation objectives (Jefferson et al., 2015).

Engaging young citizens in structured learning through group interaction with the environment under professional guidance is a comprehensive training system in which the investments could reap longstanding benefits (Hogan, 2002; Davis, 1998; Krasny & Tidball, 2009). By employing emotion, attention and concentration, CS activities augment people's knowledge and consciousness about local biodiversity (Jordan et al., 2011). Here, the "*Find invasive seaweed*" game was employed as training material that enabled high school students to learn concepts while playing and carrying out a long-term project (3 months) with researchers from the University of Oviedo in order to find and identify IAS.

Most CS project undertakings have illustrated that recruitment is one of the hardest components (Council & Horvath, 2016). Despite this, the '*Find invasive seaweed*' game enjoyed a successful recruitment rate in our pilot study among children 8 to 16 years of age (a total of 18 participants from an initial group of 12; 150%); and a more modest engagement in the case study (14 participants from an initial group of 46; 30%). The differences in recruitment might be explained by the different contexts, since the pilot study was completed during summer holidays, and the study was completed within a formal education program. In any case, conclusions about this recruitment should be made with caution because the small sampling size (n=64) and/or focus group characteristics (as it was conducted in a group of children who were living in a coastal area) could have an effect. For future studies, we recommend using a larger sampling size and different groups of study.

Educational games should challenge students (Hamari, 2016; Kavak, 2012) while allowing them to observe, explore, and manipulate a wide range of variables and receive immediate feedback on their actions (Lester et al., 2014). In the "*Find invasive seaweed*" game, several learning challenges can be found (from correctly identifying the different species of seaweed to answering specific questions about them), while students can directly manipulate, observe and explore the main learning target: invasive seaweed. Usually, educational activities require some intellectual effort, but at the same time, participants should be able to experience enjoyment and motivation (Khan & Pearce, 2015). Most educational games focus on the teaching process of a specific subject (Antunes et al., 2012; Barclay et al., 2011; Franco-Mariscal et al., 2015; Gutiérrez, 2014; Kavak, 2012; Lester et al., 2014; Martí-Centelles & Rubio-Magnieto, 2014; Russell, 1999). When playing "*Find invasive seaweed*," students can learn about marine science by acquiring knowledge about IAS and the importance of the marine environment. Moreover, there is parallel learning of bioethics, citizenship education and other subjects included in the formal education curricula (Huizenga et al., 2017). It seems that the game dynamics could help develop general competencies, such as working in groups, collaboration and reflection skills.

Recent studies have revealed that children seem to be motivated to play games not only because of the visual appearance of the game but also because of their interest in science (Iacovides et al., 2013; Curtis, 2015). Indeed, it is difficult to create an attractive educational game for the teaching-learning process, while at the same time getting students to concentrate and perform difficult tasks (Giménez et al., 2011). When developing this game, the focus was on developing an attractive game in which students could learn to identify seaweed while playing without losing interest, getting bored or getting frustrated with taxonomic issues. Children have shown positive biases for learning a large amount of new information (Lucas et al., 2014), and that was achieved during this study. It appears that students learned the difficult task of identifying invasive algae while experiencing enjoyment, motivation and involvement in a CS project. We recommend in future implementations of the "*Find invasive seaweed*" game a follow-up interview after six months with the same group of children to test long-term engagement in marine activities.

Conclusions:

In general, educational games have been shown to be an effective tool for engaging students in difficult tasks while learning. For example, the "*Find invasive seaweed*" game teaches players how to taxonomically identify different invasive species of algae and learn about their impacts while playing. Students demonstrated positive learning attitudes toward task-related environmental issues about invasive seaweeds and were able to overcome challenges, in both pilot and the case study.

The game showed positive outcomes and was included in a modest marine CS project that linked high school students with researchers. This valuable union allowed for raising awareness concerning marine conservation among students and the identification of four different invasive species of seaweed in the study area. Indeed, the game was used to foster two complementary aims: CS and at the same time knowledge, attitudes and action towards an environmental issue, invasive species and marine conservation.

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Figures captions.

Figure 1. Cards showing the seven marine invasive seaweeds occurring in the Cantabrian Sea and used in the '*Find invasive seaweed'* game in Salinas (Asturias, Spain). These cards can be modified to include local invasive species of different geographical areas.

Figure 2. Algae materials used for playing the 'Find invasive seaweed' game. A) Herbarium material from the University of Oviedo. B) Fresh samples of marine invasive algae preserved in absolute ethanol.

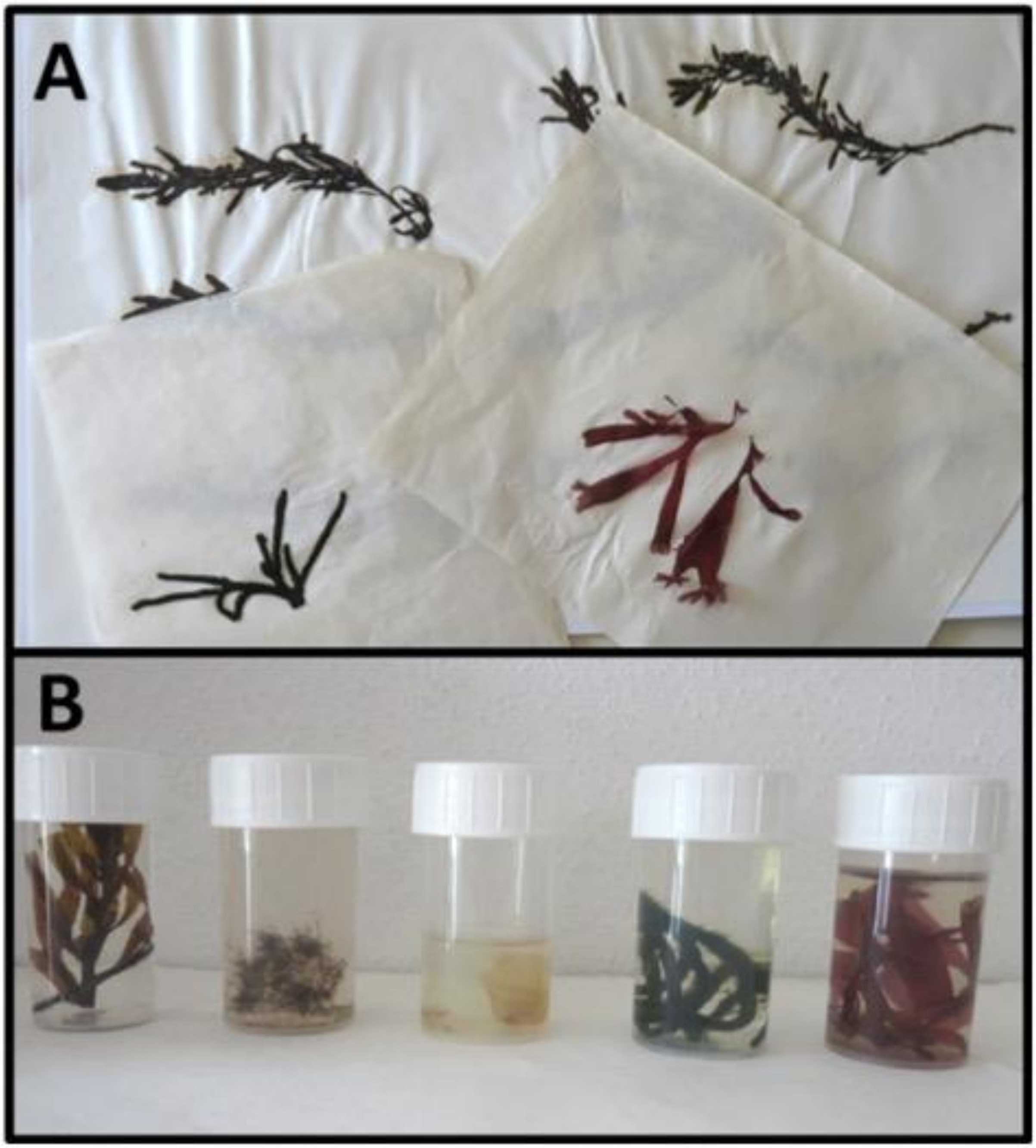

Figure 3. Evaluation of acquired knowledge(Q1, Q2 and Q3 items) about seaweeds in the game-based training with children from a secondary school of Salinas (Asturias, Spain). Answers from Q1, Q2 and Q3 items were counted, added up and presented in the pre- (blue) and post- (green) tests evaluations, its error bars and Pearson test included.

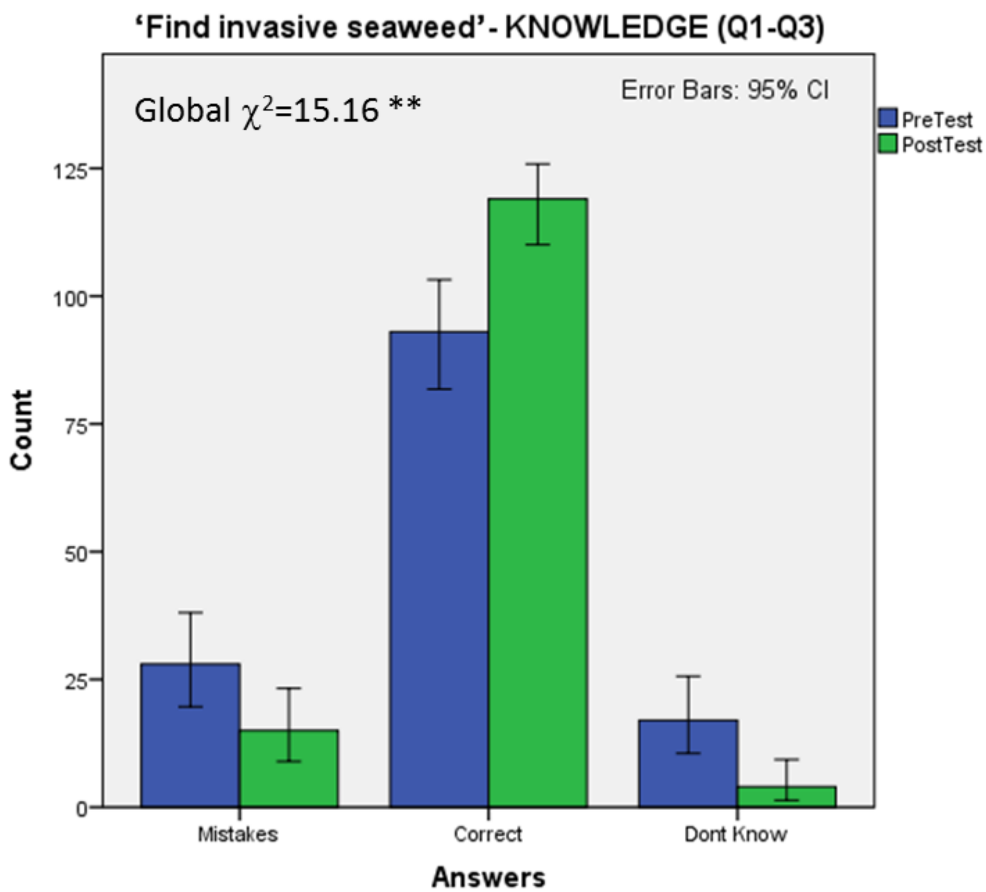

Figure 4. Comparison of Q4 (consciousness) and Q5 (management actions) mean in the pre- and post-tests evaluations when playing the ‘Find invasive seaweed’ game with children from a secondary school of Salinas (Asturias, Spain). Values are shown in a Likert scale where 1 is the lower and 4 the maximum awareness values. Kolmogorov-Smirnov values included.