Science Teaching

Cultivating future environmental stewards: a case study at John D. MacArthur Beach State Park

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Introduction

Today's environmental educators are faced with the challenging task of teaching students to be good environmental stewards. By fostering environmental stewardship, educators aim to create a constituency of informed citizens with the knowledge, values, attitudes, and skills needed to engage in environmentally conscious decisions that can help to solve environmental issues (Hungerford et al. 1998). One way to engage students of all ages in environmental stewardship is through participation in "citizen-science" programs (Dickinson et al. 2012, Cooper et al. 2007).

Citizen science uses networks of volunteers trained in the scientific process and methodologies developed by, or in collaboration with, professional scientists to assist in research (Cooper et al. 2007). These programs allow researchers to expand the spatial and temporal scope of their studies while simultaneously serving as a tool for science education and outreach (Cooper et al. 2007, Hoyer et al. 2014). Engaging the public in citizen-science activities promotes critical thinking about how present and future actions may impact ecosystem health (Dickinson et al. 2012, Hiller and Kitsantas 2014) and the effects on student-participants can be powerful. Citizen scientist programs can also be used by educators to transition traditional classroom curriculum into engaging hands-on experiences that can have lasting impacts: promoting civic engagement as adults or, potentially, sparking an interest in STEM careers (Hiller and Kitsantas 2014). Ultimately, citizen science provides a way to bridge the gap between professional scientists and the public, creating an environmentally conscious and engaged community (Dickinson et. al 2012).

In order to educate the public about the local environment with the goal of creating environmental stewards, John D. MacArthur Beach State Park (hereafter MacArthur Beach) engages citizen scientists in various monitoring projects. These programs include: quantifying sea turtle species nests; indexing biodiversity of flora and fauna; and collecting/reporting quantities of marine debris. These data are used by Park and state resource managers to monitor local and state-wide trends. For the participants, citizen-science programs such as these provide experiential and authentic learning experiences that could increase their willingness to take positive environmental actions in the future (Graham et al. 2014).

Since 1989, MacArthur Beach has been participating in the Reef Environmental Education Foundation (REEF) program (REEF 2019). The REEF program has been used to assess biodiversity and conduct population surveys of marine vertebrate and invertebrate taxa in ecosystems around the world for 25 years. In 2012, MacArthur Beach incorporated the REEF surveys into the park's summer camp curriculum to increase monitoring efforts while also using the program as an educational tool. The utilization of the REEF program in MacArthur Beach summer camps provides a valuable, cost-effective way of monitoring the environmental health of its nearshore marine ecosystem (i.e., through fish surveys), while simultaneously providing the potential to have measurable impacts on the attitudes and actions of the participants (Athman and Monroe 2001, Cooper et al. 2007, Dickinson et. al 2012, Hiller and Kitsantas 2014). In this study, we used the MacArthur Beach summer camp program to quantify student learning gains and changes in attitudes toward the environment through a research-based experiential learning activity. We argue that this program could serve as a model for using citizen science as a tool for environmental education.

Materials and Methods

Site description. MacArthur Beach is located in Palm Beach County, Florida on a barrier island between the Atlantic Ocean and the Lake Worth Lagoon (Figure 1A). It includes more than 400 acres of submerged and terrestrial habitats including: estuarine, maritime hammock, beach dune, and Anastasia limestone reef environments (FL DEP 2005). A ~1521.5 m^2 main Anastasia reef (Figure 1B) is located just offshore of MacArthur Beach (Figure 1A) and this reef was the focus of the surveys in this study. The Anastasia reef, which provides critical habitat for local biota (FNAI 2010), was formed over 100,000 years ago and is the foundation for much of Florida's Atlantic coast (Perkins 1977).

Program description. MacArthur Beach's Natural Science Education Program hosts six, one-week sessions of marine biology camp each year. The goals of the camp are to engage students in a long-term scientific study, provide hands-on training on data collection protocols, and to foster an appreciation of the local environment and an understanding of the value of scientific monitoring. Since 2012, students ages 11–17 have participated in a variety of marine-biology-focused activities including the Park's long-term monitoring of the resident fish populations through the REEF program.

During the program, students undergo rigorous training and are taught how to identify local fish species through lessons developed by the Florida Department of Environmental Protection's Bureau of Parks District 5 Biologist (Figure 1C). Training includes the teaching students fish identification characteristics such as shape, coloration, and unique markings so that they can accurately categorize the local species. The student's ability to identify and classify the fauna is assessed verbally throughout the training. Students are also trained on how to use the REEF (2019) protocols to accurately count the fish, to input data into REEF's online database, and are assessed on those protocols prior to conducting the surveys. Student observations of fish species are also reviewed for quality control by a representative from REEF after data submission.

Each year, students conducted three, ~45–60 minute snorkeling surveys at MacArthur Beach during June or July. The students observed the fish species present using the REEF methodology (REEF 2019), which categorizes each fish species as either: 1) "single (S)": one individual fish, 2) “few (F)”: 2–10 individuals, 3) “many (M)”: 11–100 individuals, or 4) “abundant (A)”: 100+ individuals. Following the survey, students immediately returned to the classroom, where their observations were entered into the REEF database. Ideally, the students would have recorded their observations in the field using dive slates; however, due to safety considerations related to the limited swimming abilities of some of the students, this was not possible. Therefore, the data entry was monitored by both the staff and the Director of Education to ensure accuracy. To further evaluate the accuracy of student observations, we compared the data from the students to that recorded on a dive slate in the field by a trained staff member (Figure 1D) during a survey in the summer of 2019. The independent data observations were identical, which provides further support that the students’ observations were accurate.

After data submission, REEF compiles all the survey information and creates a downloadable report that the user can analyze. The report includes sighting frequency (SF) of each species, which is calculated as:

$$\%SF = 100 * \frac{S + F + M + A}{Number\ of\ surveys}$$

and density of each species, which is calculated as:

$$Density = \frac{(S*1)+(F*2)+(M*3)+(A*4)}{Number\ of\ surveys}$$

We summarized these metrics for each year based on the REEF recommendations (REEF 2019) by determining the number of species that had SFs greater (high SF) or lower (low SF) than 50% and densities greater (high density) or lower (low density) than three. We also summed the number of species found at MacArthur Beach that were not observed each year. The number of species observed in the annual surveys was compared using an analysis of variance (ANOVA) in RStudio. Those data met the assumptions of normality and homoscedasticity of variance (Shapiro-Wilk test: W=0.89, p=0.06; Levene's test: $F_{4,10}$=0.54, p=0.71). We also used the density estimates from each annual survey to construct Bray-Curtis similarity matrices for comparing the fish community composition across years with an analysis of similarities (ANOSIM) using Primer statistical software.

Measuring student perception and learning gains. Students (n=36) participating in the MacArthur Beach summer camp program in 2018 were given a written test before and after participating in the program (i.e., "pre-post-test") designed to assess learning gains specific to the REEF surveys and changes related to environmental stewardship (the test is provided in the Appendix). Students were evaluated on: 1) knowledge related to the REEF program (i.e., fish identification and describing fish counts); 2) perception of the importance of citizen-science projects; and 3) interest in and perception of environmental stewardship (i.e., through participating in future citizen-science programs or pursuing science careers). Student learning gains and changes in attitudes were assessed with a paired t-test using RStudio.

Results and Discussion

The students catalogued 110 fish species during the five year study; these data are available at: https://www.reef.org/db/reports/geo?exp=&region_code=TWA&zones=33010003. On average, 30 species were observed (±5.6 SD) per survey and the total number of species observed per year varied between 45 (in 2014) and 71 (in 2016). Across all years, the species that was most abundantly observed was the porkfish with a Sighting Frequency (SF) of 93.75% (identification of this species was also assessed in the pre-post-test) followed by the sergeant major (SF=89.29%), black margate (SF=82.14%), doctorfish (SF= 78.57%), and grey snapper (SF=76.79%). There was no significant change in species diversity over time (ANOVA: $F_{1,13}=0.21$, $p=0.65$). Additionally, although there was significant temporal variability in fish species composition (ANOSIM: $R=0.261$, $p=0.03$), we did not find any significant differences in species composition in the pairwise contrasts between years (ANOSIM: $p>0.10$). Finally, based on REEF's SF and density metrics, there were no major temporal changes in species abundances (Figure 2). Together, these results suggest that the Anastasia rock reef at MacArthur Beach has maintained relatively stable fish populations since 2014. The similarity of the data among years also supports the conclusion that the students who participated in the citizen science fish survey were consistent in their data collection methods. These data, which are publicly available through REEF's open-access database, provide baseline information that can be used by park management, natural resource managers, and local scientists interested in evaluating the effect of any future environmental disturbances (e.g., harmful algae bloom or hurricane) or for any future monitoring efforts.

Our study supports previous research suggesting that participation in citizen-science programs can significantly enhance student learning and attitudes about science, while simultaneously promoting environmental stewardship (Weinberg et al. 2011). Providing students with the opportunity to collect scientific data through citizen-science programs can increase their understanding of local ecosystems, enhance their observation skills, and can improve their understanding of the scientific process (Brossard et al. 2005, Hiller and Kitsantas 2014). Indeed, based on the pre-post-test results, we found that students displayed significant learning gains in fish species identification (47.2%; t-test: $t_{35} = -5.9$, $P < 0.001$; Figure 3A). We also found a significant gain in the students' ability to identify the qualities of an environmental steward (27.8%; paired t-test: $t_{35} = -2.9$, $P = 0.006$, Figure 3B), which supports previous research suggesting that experiential learning can promote a more scientifically literate community (Weinberg et al. 2011).

Most participants in citizen-science programs have a common interest and curiosity about the subject matter with a genuine desire to advance the field of study (Dickinson et. al 2012). The cohort of students in the MacArthur Beach program were no exception. Our pre-test results showed that 88.9% of the students already understood the importance of long-term monitoring of fish populations before participating in the program, and this perception only increased by 2.8% after the program. Although the majority (61%) of the students that matriculated through our program had never before participated in a citizen-science project, many still displayed a high level of environmental awareness by indicating that they cared for the local environment (also 61% on the pre-test); however after participating in the program, 100% of the students understood the project goals and the importance of the survey to the scientific community.

Remarkably, even with the high environmental awareness of our student population, participation in our program still resulted in a significant (22.2%) positive attitude change towards citizen science and an increased desire to care for the local environment (paired t-test: $t_{35} = -2.3$, $P = 0.027$). Furthermore, the number of students who were interested in participating in citizen-science programs increased significantly, by 19.4%, after the program (Wilcoxon Sign Rank Test: $Z = -2.1$, $P = 0.034$). Indeed, our results support the suggestion that student exposure to citizen-science programs, and other environmental education programs that provide experiential learning, are more likely to be civically engaged, have interest in science-related careers, and become generally interested in future scientific endeavors (Athman and Monroe 2001, Jarvis and Pell 2005, Hiller and Kitsantas 2014). We found a significant (11.1%) increase in students interested in pursuing scientific careers (paired t-test: $t_{35} = -2.2$, $P = 0.037$; Figure 3C) after participating in our program, which supports these claims.

Overall, our study suggests that citizen-science activities are a powerful tool to alter attitudes and behaviors of people who do not have a particularly strong background or appreciation for the environment, but also for individuals who have a higher awareness of environmental issues. Environmental education through hands-on experiential learning, like the REEF citizen-science program, can help foster student learning and enthusiasm, encouraging them to think more critically, empowering them with the skills necessary to make educated decisions, and become environmental stewards in the future (Graham et al. 2014).

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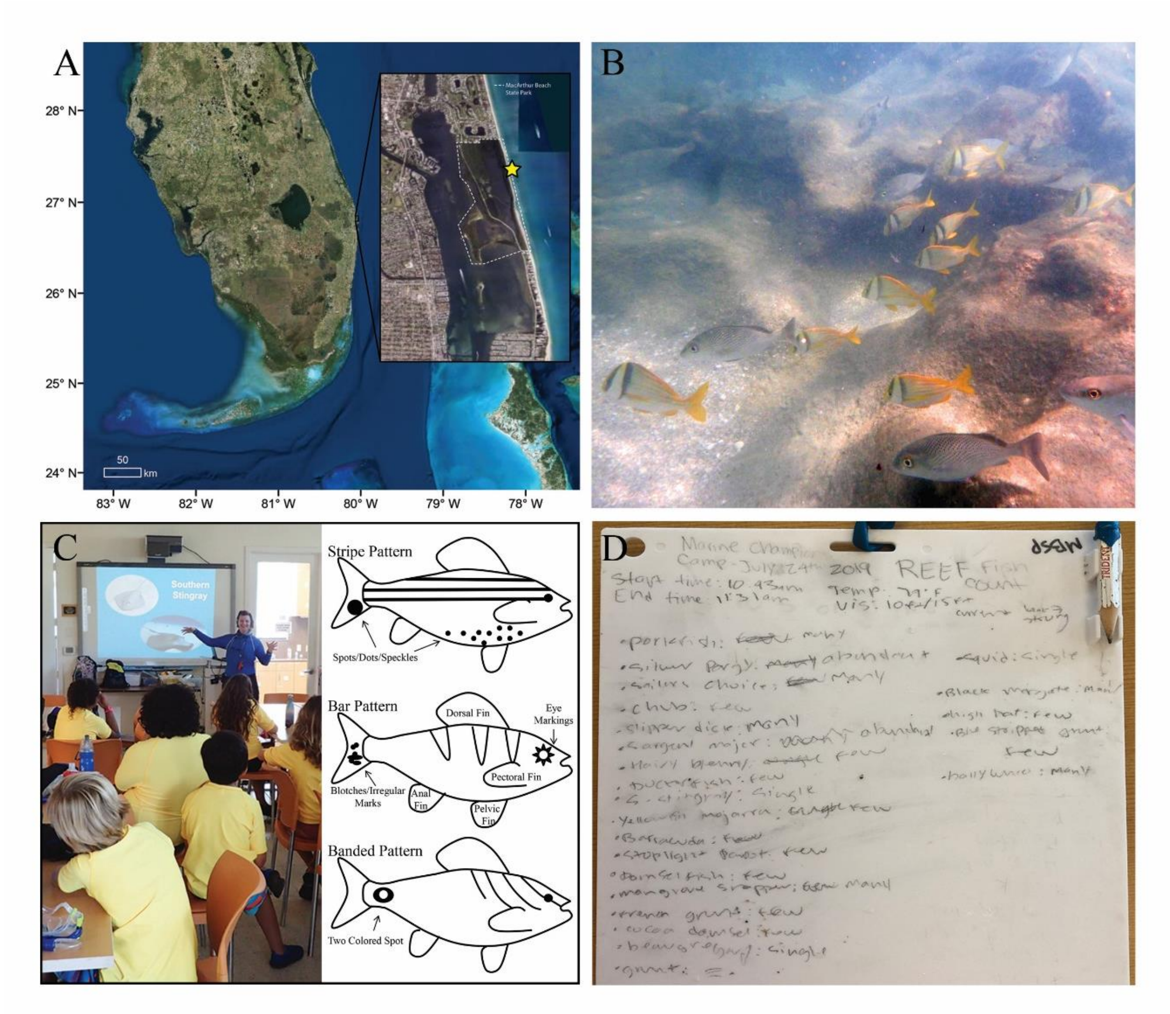

A
B
C
D
28° N
27° N
26° N
25° N
24° N
83° W
82° W
81° W
80° W
79° W
78° W
50
km
MacArthur Beach State Park
Southern Stingray
Stripe Pattern
Spots/Dots/Speckles
Bar Pattern
Dorsal Fin
Eye Markings
Pectoral Fin
Blotches/Irregular Marks
Anal Fin
Pelvic Fin
Banded Pattern
Two Colored Spot

Figure 1

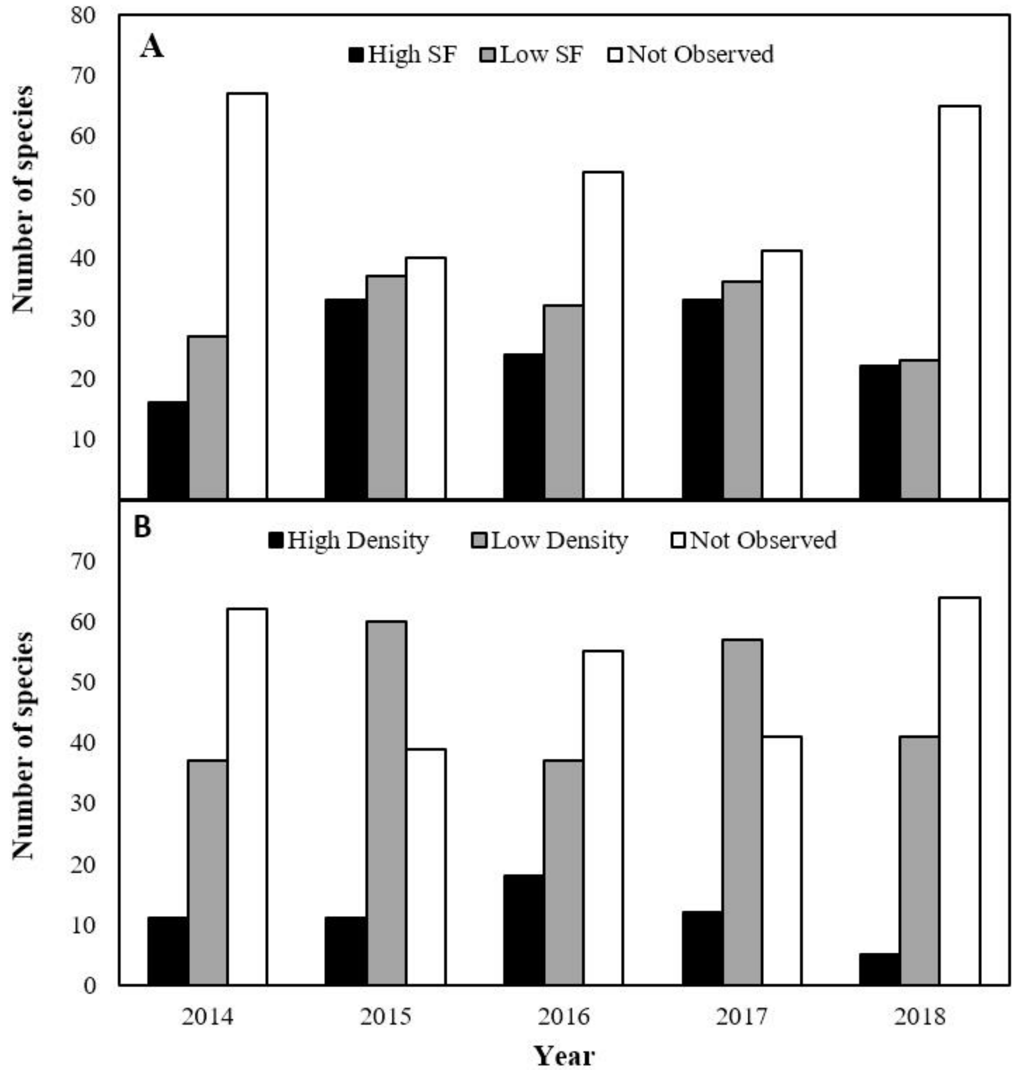
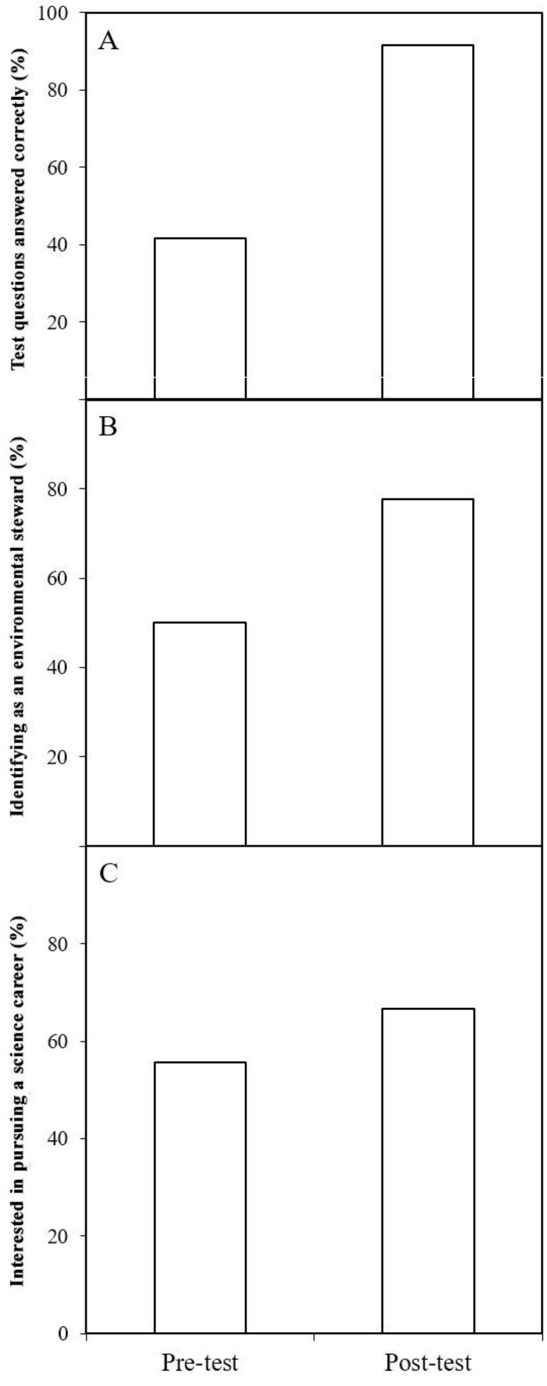

A
High SF
Low SF
Not Observed
B
High Density
Low Density
Not Observed
Number of species
Number of species
80
70
60
50
40
30
20
10
0
2014
2015
2016
2017
2018
Year

Figure 2



Test questions answered correctly (%)
100
80
60
40
20
A
Identifying as an environmental steward (%)
80
60
40
20
B
Interested in pursuing a science career (%)
80
60
40
20
0
C
Pre-test
Post-test

Figure 3

Figure 1: Map of John D. MacArthur Beach State Park (1A). The star in (1A) shows the locations of the Anastasia Limestone Rock Reef shown in (1B). 1C shows students preparing and learning species for fish count in classroom and an example of how the students are taught to identify the species based on characteristics such as fish shape, coloration, and unique markings. 1D shows a staff dive slate with fish count documentation used to assess accuracy of student data input.

Figure 2: Summary species observations based on the species abundance metrics developed by REEF. A) The number of species with high ($>50\%$) sighting frequency (SF), low ($<50\%$) SF, or that were not observed during a particular year (but are known to be present at the site) B) The number of species that had high (>3) density, low (<3) density, or were not observed during a particular year.

Figure 3: Pre-test and post-test results. A) Percentage of students who gave the correct answer on the question related to content knowledge. B) Percentage of students who identified as an environmental steward. 3C) Percentage of students who indicated that they had an interest in pursuing a science career. Each of these metrics showed significant ($p<0.05$) increases between the pre-test and post-test.

Appendix: John D. MacArthur Beach State Park Summer Camp Pre-Post Test

Name: ________________________
Date: _________________________
Age: __________________________
Female or Male (circle)

1. What is the common name of the fish pictured here?

   a. Parrotfish
   b. Porkfish
   c. Porgy
   d. Piranha

2. On a scale of 1 (not important) to 5 (very important), how it important do you think it is to collect data (information) on the animals and plants found in the reef ecosystem?

1	2	3	4	5
(not important)		(neutral)		(very important)

3. Have you ever participated in a citizen-science project before? (Circle Yes or No)

   Yes No

4. How do you think participating in citizen-science activities (like fish counts) affects how you feel about the environment?
   a. Citizen science makes people care **much** more about the environment
   b. Citizen science makes people care **somewhat** more about the environment
   c. **No** impact
   d. Citizen science makes people care **less** about the environment

5. What is a "fish count" and what do you think scientists do with them?
   (Short answer response)
   ____
   ____
   ____

6. How interested would you be in assisting scientists with gathering information about the reef in the future?
   a. **Very** interested
   b. **Somewhat** interested
   c. **Not** interested

7. On a scale of 1 (not interested) to 5 (very interested), how interested are you in pursuing job in the science field in the future (i.e. marine biologist, chemist, zoologist, etc.)

1	2	3	4	5
(not interested)		(neutral)		(very interested)

8. What does “stewardship” mean?
    a. Looking out for or taking care of something
    b. Being a good person
    c. Working in a science field
    d. Working in the marine environment specifically on a boat

9. What is one way that you could be a good steward of our oceans? (Short answer response)

    ____
    ____
    ____

10. In your opinion, what is the best part of the MacArthur Beach Summer Camp?
    a. Science activities
    b. Kayaking
    c. Snorkeling
    d. Other activities/games