Informal Science Education (ISE): An approach for engaging communities in understanding beach processes in Puerto Rico

By

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ABSTRACT

Researchers performed a study on beach geomorphic characteristics (beach width and sediments) to determine the association of beach processes with river flow using an Informal Science Education (ISE) approach. The objectives were to: 1) develop an ISE model by using a citizen structured framework for conducting data collection, data entry and analysis, communication of results, and development of co-creator community coastal projects; and 2) assess the learning process of community members or citizen scientists throughout the duration of the coastal ISE project. Three beach assessment protocols (field data collection of beach geomorphology, laboratory analysis of sediments, and data entry/analyses and dissemination of results) were designed and performed with project participants. In the two-year period, 279 individuals were recruited and engaged to participate on a voluntary basis. Of these, 72 participants (or 26%) had recurring participation in any one or a combination of the three protocols for a total of 581 participations. Knowledge and skills gained by participants included monitoring beach systems using beach profiling and sea water salinity monitoring approaches, identifying types of coasts and their components, using global positioning system (GPS), collecting and analyzing beach sediments and analyzing the data set for beach planning and management. The findings on the participant ISE learning process showed that after participating in any of the project protocols participants were: 1) committed to continuous voluntary participation in coastal studies; 2) increased in numbers and in frequency to engage actively as informal research assistants and leaders; and 3) gained knowledge and proficiency on beach components and beach processes. Also, through this project participants: 1) served a key role in identifying sediment characteristics that were fundamental to evaluating the relationships between beach morphology and river processes; 2) co-created community citizen science projects; and 3) became empowered citizen scientists to effectively communicate research findings to their community. We therefore conclude that this ISE model is an effective tool to engage citizens and change their behavior and attitude towards coastal processes and the connectivity between rivers and beaches.

ADDITIONAL KEYWORDS: Informal science education, beach studies, learning assessment.

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Informal science learning and education occurs outside of formal school settings and is focused on engaging individuals from all walks of life and with diverse profiles (age, gender, education, working status, etc.) by bringing science to the communities. This model has been used during the past 45 years by educational, governmental, and private institutions to, among others, help museums produce television and radio programs and traveling exhibitions and expositions (Ucko 2010). Studies that use informal science approaches, especially citizen science, include developing telecommunication systems prototypes (Scowcroft *et al.* 2015), chemistry demonstrations (Petkewich 2008), space education curricula (Crawford and Huscroft-D'Angelo 2015), robotics (Phamduy *et al.* 2015), ecology studies (Lowman 2014; Verderber 1993), geographic information system (GIS) technologies (Barnett *et al.* 2010), and biodiversity monitoring (Loos *et al.* 2015).

Publications related to coastal studies using the informal science approach are few and even more so for beach geomorphological assessment. The limited available research on informal science focus mainly on coastal estuary studies (Green *et al.* 2013), on coastal management dissemination materials (Milne *et al.* 2004) and on climate change (Shaw *et. al.* 2013). The goal of our study was to use informal science to understand how a river system impacts beach geomorphological processes on a tropical island. Researchers, together with community members or citizen scientists, assessed beach width, terrigenous/biogenic sediment composition, and mean grain size in two beach systems near the Río Grande de Manatí river mouth in northern Puerto Rico. Terrigenous sediment refers to sediments that have more than 75% of material derived from erosion on land,

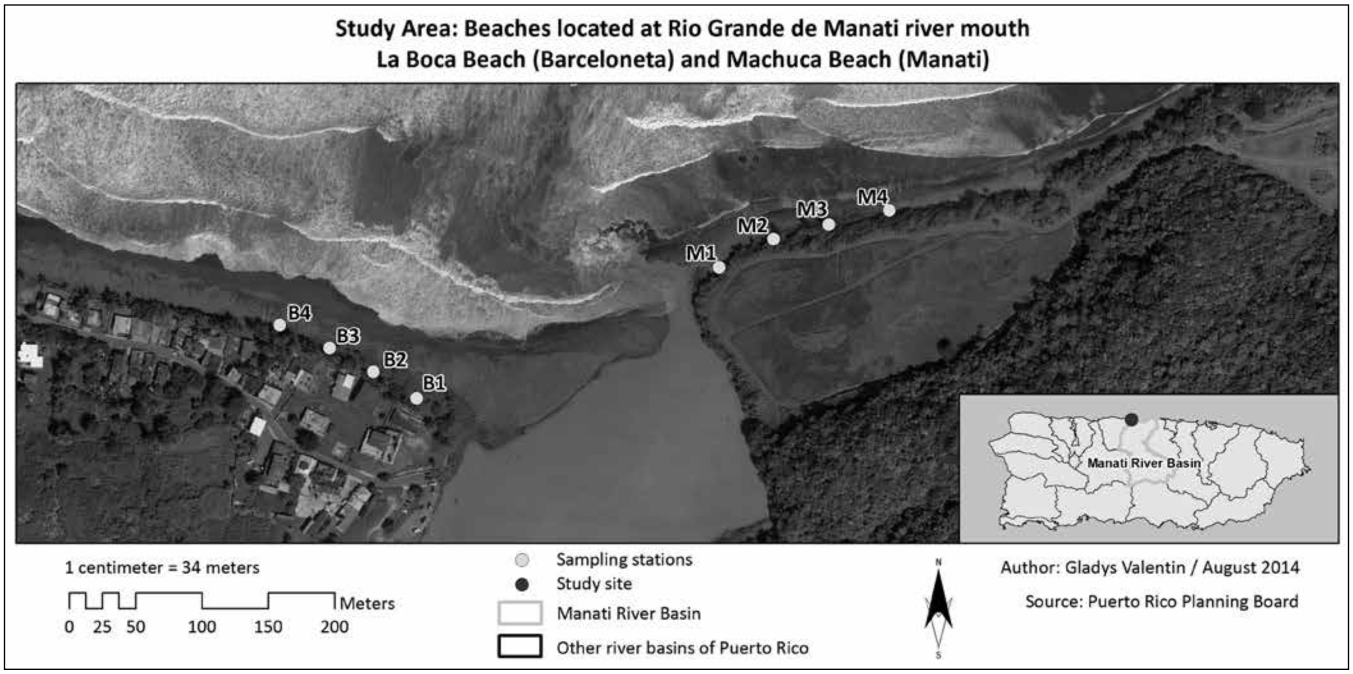

Figure 1. Study site and sampling stations.

while biogenic sediment refers to matter with more than 75% of material derived from marine organisms.

Understanding the role of river dynamics/discharge in beach geomorphology is important to citizens of Puerto Rico, especially in light of the island's vulnerability to climate change and sea level rise. Citizens were engaged in this project to answer the following broader research questions: 1) What are the beach geomorphic characteristics — beach width and sediment (grain size and composition) — in two beach systems located near the Río Grande de Manatí river system? and 2) What are the possible associations between river flow and the beach geomorphic characteristics at these two beaches? Here the focus of citizen engagement was multifaceted. The objectives were to: 1) develop an ISE model by using a citizen structured framework for conducting data collection, data entry and analysis, communication of results, and development of co-creator community coastal projects; and 2) assess the learning process of community members or citizen scientists throughout the duration of the ISE project.

AN INFORMAL SCIENCE BEACH STUDY

A beach geomorphic study titled "The Use of Beach Sediments (composition and grain size) as an Indicator to Identify the Impacts of River Processes along the Río Grande de Manatí Watershed" was conducted during two years at the Manatí and Barceloneta municipalities of Puerto Rico (2013-2015). The study was performed at Machuca Beach and La Boca Beach. Both are located on the Río Grande de Manatí river mouth at the north-central coast of Puerto Rico at Barrio Esperanza, Manatí municipality, and Barrio La Boca, Barceloneta municipality (Figure 1). Machuca Beach is located at the east side of the Río Grande de Manatí river mouth. This beach is part of Hacienda La Esperanza Nature Reserve, a historic sugar cane property managed by the Conservation Trust of Puerto Rico since 1975.

Machuca Beach is mainly a mix of carbonate and terrigenous sediments. The beach plain is delineated in the nearshore by beach rock (sedimentary rock), eolianites (cemented dunes) and marine terraces (surface of marine origin). Insolated corals, seagrass and algae beds were observed along the insular platform. Main coral species found in the area were: *Acropora palmata*, *Siderastrea radian*, *Siderastrea sidereal*, *Porites porites*, and *Porites astreoide* (Torres, pers. obs. 2010). Also, *Thalassia testudimun*, brown, red and green algae were found in the nearshore area. Wave regime was highly characterized by the presence of seas and swells coming from the North Atlantic and waves generated by tropical storms. West of the beach plain the Río Grande de Manatí contributed terrigenous sediments to La Boca Beach system. This beach was exposed to the northern seas and swells without natural barriers such as eolianites and beach rock in its nearshore area.

The following were the objectives achieved in the development of an ISE model.

Objective 1: Beach study protocols developed for Informal Science Education

The researcher together with assistants successfully designed a user-friendly beach assessment protocol to be used by researchers and community members (citizen scientists) to collect, manage, and analyze data through an ISE approach.

For the Citizen Science project were developed detailed specific strategies of recruitment and retention within four target underrepresented, underserved municipalities to increase inclusion and foster greater diversity of participants. The communication and marketing strategy to recruit participants to pass through contributory, collaborative, co-created phases of ISE incorporated materials with catchy, attractive designs blended with simple language about relevant community environmental issues through multimedia. Also, it included the following strategies: 1) paper flyers to be distributed in frequently visited areas within municipality such as shopping malls, stores, libraries, and municipality buildings; 2) for retention, volunteer leaders were recruited to give follow up telephone calls to one time participants;

and 3) open house for family members of repeat participants to encourage participation and return to projects.

Three main activities were designed to carry out the study with project participants to determine the relationship between beach geomorphic components (beach width and sediment grain size and components) and river flow (m^3). The protocols were: field data collection of beach geomorphology, laboratory analysis of sediments, and data entry and analyses. The protocol on beach geomorphology included collecting geomorphologic and environmental beach data. Through a systematic sampling method for both beaches, four permanent stations 50 m apart were selected starting from the beach plain near the river mouth (Figure 1). The protocol entailed measuring beach width, seawater salinity and density, and collecting beach sediments on a monthly basis. Beach width was measured with a metric tape starting from the vegetation line and/or dune base to the wet or water line (perpendicular orientation) (Figures 2 and 3). Beach sediment samples were collected at the back-beach and swash zone (wet line) for each permanent beach station. Field photography, videos and notes were collected as supporting materials for each field visit.

The protocol for laboratory analysis of sediments included analyzing sediment grain size and components (biogenic and terrigenous) from the samples collected. Grain size distribution was performed through sieving analysis (mesh size range from -2 to 3.5 phi) as defined by Folk (1980) (Figure 4). Analysis of sediment components was conducted with 10% chloride acid solution.

Data entry and analyses consisted of: 1) uploading to the project's website (www.ciudadanocientifico.org) geomorphic/environmental data and sediment grain size and composition; 2) performing a geologic evaluation of the Río Grande de Manatí watershed; 3) preparing histograms and cumulative graphs on sediment grain size based on Folk parameters, and 4) evaluating published river flow data. Conferences, workshops, and individual meetings were held to support project participants, better known as citizen scientists, with their performance throughout this stage of the project. Participants were trained on the use of the beach protocols and to effectively communicate results. Furthermore, participants were encouraged to become collaborators and co-creators. For this project the researcher defined collaborators as individuals from the general public involved in analyzing data, refining project design, and communicating findings with the researchers. Co-creators were defined as individuals from the general public that have the ability to perform collaborator tasks as well as develop and implement their own community-based scientific project. The main researcher maintains continuous communication between research assistant, collaborators, and co-creators to assure quality data acquisition during the protocol's execution by the participants (monthly meetings). In addition, the research assistants validate the data entered into the databank by the participants. This validation process is important to maintain the scientific data quality as required by the peers.

Figure 2. Vegetation line for start of beach width measurements.

Objective 2: Engage the public in conducting beach assessments

Citizen Scientists' Profile: In the two-year period 279 individuals were recruited and engaged on a voluntary basis. Of these, 72 participants (or 26%) had recurring participation in any one protocol or a combination of the three protocols for a total of 581 participations. Participant age ranged from 6 to 74 years with a mean age of 32 years. Frequency distribution showed that individuals 17, 20 and 21 years of age participated the most in this project. Individuals between 20 and 23 years and between 41 and 45 engaged largely in the monthly beach geomorphic and environmental data collection activities, while teenagers and retirees engaged primarily in the laboratory activities.

The adult participants were active professionals dedicated to government services, private education, and pharmaceutical industries. The majority of this project's citizen scientists came from local areas of Puerto Rico, namely the municipalities of Arecibo, San Juan, Manatí, Bayamón, and Carolina. During seasonal periods, such as summer and winter, individuals from the United States also participated as citizen scientists. The majority of participants did not have previous experiences in beach studies or research studies that identify the connection among river and beach systems before their participation in this project.

Throughout the two-year project period, citizen scientists had the opportunity to collect and analyze 368 beach sediment samples from the back-beach and swash zones, to take 208 beach width measurements and to measure 192 samples for salinity and seawater density. Repeat citizen scientists who engaged in all project protocols also engaged actively in communicating findings at local, national, and international arenas. Citizen scientists significantly contributed towards the broader research findings, which showed evident differences in beach width, beach sediment grain size, and composition at all beach stations located at both sides of the river mouth. Also, participants had the opportunity to identify and under-

Figure 3 (right). Swash zone identification for beach width measurements.

Figure 4 (below). Sediment size sorting by citizen scientists in the laboratory.

stand diverse associations between each beach's geomorphological components (beach width, terrigenous/biogenic content, and mean grain size) and the Río Grande de Manatí river flow events (daily and monthly means) in the study site. Some of the associations identified between river flow and beach component characteristics were: 1) narrower subaerial beaches were measured during major flow events; 2) major terrigenous component was documented during major river flow events; and 3) coarser sands were found in beaches located near the river mouth during high river flow events.

Through the three coastal protocols developed for this ISE model the researcher successfully: 1) trained community members on coastal studies protocols and scientific analyses; 2) educated community members on the importance of beach-river system relationships; 3) encouraged community members to engage as project participants and leaders; 4) produced an educational materials package, including beach and river assessment tool kits; 5) promoted coastal studies as a field that helps community members to participate in the discussion of coastal issues in Puerto Rico; and 6) encouraged individuals to replicate the project's protocols in other coastal communities.

These objectives were measured by evaluating citizen scientists' learning process and changes in knowledge, skills and attitudes as they engaged in the beach studies project (Estremera 2015). Special attention was placed on the impact that such learning would have on the protection of nature in the community at large. The evaluation used a mixed, non-experimental design with a descriptive and longitudinal scope within a natural environment (Frechtling *et al.* 2010) during a two-year period. The evaluation sought to answer the following question: Does informal science education (ISE) promote knowledge, skills, attitudes and behavior that leads participants of the beach studies project to become co-creator citizen scientists? The design included impact evaluation to assess if the learning objectives were met (Bloom 1981).

The design also considered unforeseen or collateral effects (Verdung 1997) such as participant interest in engaging in other projects, coming together of families by parents participating with their children in the project, and forged relationships between participants and the researchers and other citizen scientists, among others. In addition to learning concepts, participants became involved in other processes that transcended knowledge itself. Triangulation via a questionnaire, rubric, and check list was used to evaluate the following dimensions of the study: knowledge, scientific skills and attitudes, communicating the scientific research, and behaviors to co-create scientific projects.

Table 1.
Knowledge and skills self-reported by participants when first starting in the coastal project (n = 72).

How proficient am I regarding these knowledge and skills?	Proficient	Not proficient
1. Use of measuring tape, refractometer, global positioning system (GPS) and sediment collection.	21	49
2. Knowledge of the beach, parts of the beach, coast, beach and river sedimentology, sediment sources (river vs. ocean).	26	46
3. Characterize sediment composition (qualitative by observation).	16	56
4. Perform granulometric tests using sieves and prepare charts.	13	59
5. Identify minerals using a stereoscope and take images.	10	60
6. Identify sediment composition using HCL solution.	7	62
7. Manage database information: precipitation, river discharge and building permits.	12	57
f = 494	105	389
Percent	21%	79%

KNOWLEDGE, SKILLS, AND ATTITUDES TOWARDS SCIENCE (INFORMAL SCIENCE PROJECT ASSESSMENT)

Scientific knowledge, skills, and attitudes were evaluated with a Likert scale questionnaire that was administered to citizen scientists at the two different stages: contributor (n = 72) and co-creator (n = 5). Also, the evaluators completed the rubric to evaluate the co-creators (n = 4) scientific skills as they passed through the different stages of citizen science. The evaluation findings provided answers to three of the beach project objectives: 1) to understand basic knowledge on the principles, concepts and scientific process and

Table 2.
Knowledge, skills and attitudes that co-creators self-reported when they started in the coastal project and then finalized (n = 5).

How proficient am I regarding these knowledge and skills?	Before: Proficient	Before: Not proficient	After: Proficient	After: Not proficient
1. Use of measuring tape, refractometer, global positioning system (GPS) and sediment collection.	3	2	5	0
2. Knowledge of the beach, parts of the beach, coast, beach and river sedimentology, sediment sources (river vs. ocean).	4	1	5	0
3. Characterize sediment composition (qualitative by observation).	3	2	5	0
4. Perform granulometric tests using sieves and prepare charts.	3	2	5	0
5. Identify minerals using a stereoscope and take images.	2	3	4	1
6. Identify sediment composition using HCL solution.	1	4	5	0
7. Manage database information: precipitation, river discharge and building permits.	2	3	4	1
f = 35	18	17	33	2
Percent	51%	49%	94%	6%

Table 3.
Researcher's evaluation of co-creators and collaborators regarding proficiency in scientific research skills in the coastal project.

	Before			After		
Research areas (n = 4)	**2**	**1**	**0**	**2**	**1**	**0**
1. Choose and define a research question or problem	4	0	0	4	0	0
2. Collect information on a research question or problem	4	0	0	4	0	0
3. Develop a preliminary explanation or plan to address a research problem, hypothesis or question	4	0	0	4	0	0
4. Design methodology to collect data or a strategy to address a problem	3	1	0	4	0	0
5. Collect information from samples and/or record data and analyze findings	2	0	2	4	0	0
6. Interpret data and infer conclusions	2	0	2	4	0	0
7. Report conclusions and translate results into action	2	0	2	4	0	0
8. Share results with others and formulate new questions	2	0	2	3	0	1
f = 32	23	1	8	31	0	1
Percent:	72%	3%	25%	97%	0%	3%

method techniques used in the project; 2) to apply basic research techniques to collect and analyze data for the project; and 3) to show interest in analyzing the effects of urbanism on the ecosystems surrounding the Río Grande de Manatí watershed.

At the contributor level, 72 project participants were evaluated on eight principles of knowledge and skills (e.g. knowledge on beaches, coasts, sedimentology, and rivers; use of metric tape, refractometer, and GPS; sediment collection, granulometry testing, managing data base information, and others) (Table 1). These findings showed that over three quarters of the contributors who started the program were not proficient in knowledge and skills in scientific matters related to the coastal project.

At co-creator level, five citizen scientists were evaluated for knowledge and skills gain at the beginning and end of two years. Here participants self-reported a 43% gain in knowledge and skills – from 51% (before) to 94% (after) (Table 2). The effective use of technology and teaching materials in the tool kit from maps to technology enhanced field experiences and resulted in knowledge and skills gained (http://ciudadanocientifico.org/cc2/cos12-15/tool-kit/). The researcher used cloth maps (geology, rivers, and land use) of the watershed in the field to orient citizen scientists on the connectivity between rivers and beach geomorphological processes. Also, the use of various easy-to-use instruments such as sieves, scales, and ovens, and the presence of the researcher throughout the scientific process facilitated the learning process. Further, open, informal, and democratic dialogue between researchers, repeat participants, and first time participants ensured peer to peer, student to professor, and participant to researcher teaching and learning processes (Estremera 2015).

CO-CREATING SCIENTIFIC PROJECTS

By the end of three years five community-based citizen science projects on coastal processes were developed.

1) "A Study of Beach Geomorphology at Ocean Park Beach, San Juan, Puerto Rico," (September-December, 2014). Here the co-creator developed a partnership with the local chapter of a student environmental group, Society of Marine Environment, to participate in monitoring and analyzing beach sediments.

2) "Understanding Beach Geomorphology Changes at Two High Traffic Tourist Beaches at Culebra, Puerto Rico."

3) "Comparative Study of Beach Morphology (beach width, grain size and composition) in Two Beach Systems at Río Grande de Añasco and Río Grande de Manatí, Puerto Rico."

4) "Combining Two Citizen Science Scientific Methodologies to Study Coastal Erosion as an Agent of Geomorphologic Change and Loss of Archaeological Context," and

5) "Assessing Coastal Area Tsunami Vulnerability in the Municipality of Dorado, Puerto Rico."

In each co-creator project, the researcher evaluated collaborators and co-creators on their ability to perform research using scientific methodology and on their skills to communicate results. A rubric consisting of eight steps of the scientific method was used. The steps included: formulating problems for study, collecting information on the problem, developing hypotheses and designing methodology, among others. The instrument was administered on two occasions: December 2014 and June 2015. By the end of the beach project, 97% of collaborators and co-creators adequately applied the required research skills. After participating for two years in the beach project co-creators and collaborators showed a 25% gain in scientific skills: methodology design, collecting information from samples, data recording and analysis, interpreting data and drawing conclusions, communicating conclusions, translating results to action, and having conversations about the results with others and formulating new research questions. It is worth noting that these are the most complex skills in the scientific process. The increase in knowledge from before to after participation in the project ranged between 25% and 50%.

Five scientific attitudes (responsible use of rivers, conservation, environmental responsibility, honesty and objectivity in analyzing scientific information, and interest in performing studies on contaminated discharges and others) were evaluated using questionnaires. At the end of the educational and research process, project participants demonstrated 100% gain in pro-environment attitudes and pro-scientific efforts in favor of the environment. After the two-year proj-

Table 4.
Co-creators' attitudes towards the conservation of the Río Grande de Manatí.

How much do I value the following statements?	Before Value	Before Little or no value	After Value	After Little or no value
1. I can describe how to use rivers responsibly and how to conserve them.	3	2	5	0
2. I consider people who discharge contaminants into rivers irresponsible.	4	1	5	0
3. I prefer to be objective and honest when searching for and analyzing scientific information.	5	0	5	0
4. I am interested in performing studies on contaminated discharges that affect rivers.	4	1	5	0
5. I believe that organizing as a community is a means to defend the natural environment.	4	1	5	0
f = 25	20	5	25	
Percent	80%	20%	100%	

ect period participants showed a 20% increase in attitudes on environmental awareness and scientific citizenry (Table 4).

COMMUNICATING SCIENTIFIC RESEARCH TO CITIZENS

To engage the public in discussion about coastal process in Puerto Rico, a scientific communication strategy was developed. The evaluator performed an evaluation to determine the different communication mechanisms used by collaborator and co-creator participants. Project participants documented 14 activities with general objectives to educate, provide guidance, communicate information, and present findings. Participants used the following communication mechanisms: gave talks, used web pages, wrote newspaper articles, collaborated with the scientist in preparing articles for publication, co-presented at conferences, developed materials to be presented at conferences and science fairs, and prepared flyers on findings to be distributed in the community.

Citizen scientists participated in 57% of the project's community outreach strategy and reported an interest to participate in 43% of other events that were being conceptualized. Of these activities 43% was communicated to academic experts in the field. Seven percent (7%) of the activities focused on communicating scientific information to an audience with general knowledge of the topic (diffusion process) and 50% of the activities focused on communicating to a non-expert audience (divulging process). The latter used uncomplicated and straightforward language that could be easily understood by the general public.

The communication process in the ISE model was crucial to succeeding in engaging the communities surrounding the Río Grande de Manatí. Designing and developing an effective communication strategy occurred through a collaborative process between scientist and co-creators. The researcher ensured the scientific rigor while the co-creators provided language style and included cultural components that facilitated easy understanding of research findings. The lead researcher of this citizen science project encouraged and empowered co-creators to present at academic congresses and to expert audiences to support their citizen science community projects.

IMPACT OF SCIENTIFIC PROJECTS LED BY CO-CREATORS

The types and complexity of projects developed by co-creators indicates that citizens can engage in scientific research at the highest levels. The goals of the co-creators of this project were to achieve social impact in the community through citizen science. Co-creators viewed research from a pragmatic standpoint, where research findings could be used to address certain environmental problems within their community. It was evident that these co-creators were very interested in the educational and community purpose of the scientific projects they participated in. The concept of community citizen science was highly valued among collaborators, co-creators, and researchers alike.

Co-creator participants received many acknowledgements for the research that they performed. The project entitled "Informal Science: An Evaluation of Coastal Geomorphology at Ocean Park Beach, San Juan, Puerto Rico," presented by co-creators at the Annual Meeting of the American Association of Geographers (AAG) held in Chicago, IL, on 20-25 April 2015 received second place for the Psuty Award.

CONCLUSIONS

Citizen scientist participants, collaborators and co-creators played an important role in developing and validating ISE protocols to successfully monitor the beaches in Puerto Rico. They learned in detail the real physical and social scenarios related to coastal risks within their communities, and were prepared to address those scenarios accordingly. As a part of this process, participants, collaborators and co-creators were well-trained to understand the actual scenarios of sea level rise, human activities impact over coastal components, and the effect of swells associated by cold fronts and tropical storms at Puerto Rico. Also, citizen scientists learned the importance of beach-river and watershed temporal and spatial dynamics.

The evaluation findings showed that the objectives of the beach studies project were met. Collaborator and co-creator participants demonstrated significant gains in knowledge, skills, and scientific values by the end of the educational and research processes. In addition, collaborators and co-creators communicated scientific information at varied sectors in support of the natural environment by means of divulgation to the general public, diffusion to an audience with general knowledge on the topic, and dissemination to an expert audience. Communicating conclusions and discussing results with others is crucial to the ISE model, where co-creators of this beach project succeeded in both. Finally, the co-creators carried out numerous community science based projects in coordination with the researcher. This confirms the change in their behavior and attitude towards science and working to serve their communities.

The researchers recommend the use of this ISE model to increase community participation in academic outreach activities as well as in discussions and decision making processes relevant to local and national issues. Also, this model will use in the execution of coastal projects where the participation of community members will be important to solve policy and management issues. The participation of citizen scientists is valuable to: 1) maintain continuous observation and data acquisition in community sites; 2) incorporate community participation as a part of the outreach goal; and, 3) have detailed knowledge of their real environmental/social needs. The ISE model enlists community participation in important coastal management and is aligned to the National Policy on Oceans, Coasts, and the Great Lakes (The White House 2009). Scientists, staff members from Para La Naturaleza (nonprofit organization) and community members used findings of this project to encourage government, private, and nonprofit organization to insert communities in the decision process forums related to coastal management in Puerto Rico.

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