Citizen science: An Emergent Approach for Informal Science Education (ISE) Model and Pedagogy in Puerto Rico

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Abstract

There are different approaches in citizen science to engage that public in science from data collection, analysis and dissemination. Here we explore the informal sciences education (ISE) model and the pedagogy of citizen science, with a case study for Hispanic audiences in Puerto Rico. The assessment included multiple instruments viz. document reviews, field observations, interviews and focus groups. The hierarchical processes and pathways that result in a successful ISE citizen science project include strong administrative support with clearly defined goals and objectives; well planned and implemented scientific research projects and multiple teaching strategies to fully engage participants at the contributor, collaborator and co-creator level of participation. The pedagogy of citizen science for Hispanic audiences is based on non-formal education that uses inquiry-based models to engage the public. The combination of the citizen science project team with clear and concise educational goals in a structured citizen science framework is a powerful tool to obtain meaningful, useful, and relevant scientific data to address real-life ecological and environmental problems

Keywords: citizen science pedagogy, teaching strategies, informal science education model

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Introduction

Environmental education is believed to bring about change in behavior of people by providing them the knowledge about the environment and its issues (Hungerford & Volk, 1990). The pedagogic approach in formal educational models is to bring about behavioral changes by providing information using traditional instruction methods that is teacher centered. Formal education models are presented in systemized, structured format that is administered within norms and laws (Dib, 2007). When a global scale evaluation was done on the impact of environmental education it was found that many of the traditional instructional methods failed to develop skills associated with investigating and evaluating issues or with responsible citizenship (Hungerford & Volk, 1990; Hungerford & Volk, 2003).

In recent years non-formal educational models with flexible curricula and methodology that is adapted to the needs and interests of the students have been the instructional methods for environmental education. Lord (1999) found that when traditional teacher centered (formal) instructional method was transformed to constructivism (non-formal) that is student centered, students performed better on exams and participated more in environmental support efforts. However, informal education, a type of non-formal education (Dib 2007) which is least structured, is ideal for teaching environmental education that results in the development of necessary skills in citizens to evaluate environmental issues and become responsible citizens.

Adopting informal philosophy, citizen science in recent years has become a common tool to engage citizen to increase scientific knowledge across spatial and temporal scales, as well as to develop environmentally responsible actions towards nature and conservation (Lewandowski

2015; Shirk et al 2012). Citizen science is the engagement of citizen participants at all levels of engagement in scientific research, from data collection to analysis and dissemination (Miller-Rushing, Primack & Bonney 2012). Dickson et al (2012), describe citizen science as an indispensable means of combining ecology with environmental education and natural history using research. While instructional methods within the formal constructivist model has been widely documented to include lectures, laboratory, community-based activities and research projects (Haury 1993; Kirschner, Sweller & Clark 2006) little research has been carried out to document the educational model of informal science education (ISE) and the pedagogic techniques used by researchers and scientists to engage public in scientific projects (Sachs, Super & Prysby 2008). In this paper, we present a case study in Puerto Rico used to develop an emergent educational model with pedagogic components and their interactions for a successful citizen science project for Hispanic audiences.

The Conservation Trust of Puerto Rico (CTPR), wanted to change citizen attitude towards nature as their mission is to create stewards of nature. Historically the CTPR adopted the strategies to increase public understanding of science through educational talks and walks in Natural Protected Areas and teacher workshops, combining theory and field component. Though the CTPR received almost 60,000 visitors annually, few visitors were engaged in activities related to the advocacy for the protection of nature in their communities and neighborhoods. To engage citizens in understanding the value of nature, in 2008 the CTPR adopted citizen science approach through Informal Science Education (ISE). Through funding from National Science foundation (NSF #0638966) the research team focused on engaging citizens not only to collect scientific data on biodiversity within a Natural Protected Area, Hacienda la Esperanza (Figure1), but also significantly changed the attitude of participants about nature within the scientific projects (https: www.cuidadadanocientific.org).

The ISE approach used by the CTPR adopted the 9 steps for citizen science projects used by the world renowned eBird project (Bonney et al. 2005) viz: 1. Choose a scientific question, 2. Form a scientist/educator/technologist/evaluator team, 3. Develop, test, and refine protocols, data forms, and educational support materials, 4. Recruit participants, 5. Train participants, 6. Accept, edit, and display data, 7. Analyze and interpret data, 8. Disseminate results, and 9. Measure the outcomes. (Bonney et al. 2005). The above approach to citizen science was foreign to the scientist and the citizen scientist (participants) in Puerto Rico. Therefore, to control and ensure data quality, scientists from the five biodiversity/ecological projects within the Natural Protected Area of Hacienda La Esperanza (Figure1) opted to always be present with citizen scientists. Data was collected by the scientists and citizen's participants (one time and repeat) who were together for the entire project (2 years). These additional steps deviated from traditional citizen science projects where the scientist trains participants to identify birds, are given a tool kit and are sent off to carry out their own observations, which are later provided to the scientist or uploaded on a virtual database. Further, citizen participants contributed to method revision and developed side projects to enhance the scientific projects and data collected. While the implementation team for traditional citizen science projects consists of scientists and citizen participants, in this project the CTPR expanded the components of the ISE team to include administration staff, logistical staff, interpreters and scientist's assistants for project design, implementation and dissemination.

During the design, implementation, and the measurement of the impacts of the citizen science project, the CTPR began to observe significant differences and outcomes when implementing citizen science for Hispanic audiences. There were 2500 participants, many of whom repeated participation within one of the five ecological projects (60% retention). One participant attended 113 citizen science activities, some provided suggestions to researchers to improve scientific protocols using local traditional knowledge, one developed a species guide to crabs and a crab exhibit to highlight the management concerns for the species. Further, the "day to day" interactions between scientist and participants strengthened the engagement of participants and there was a perceived increase in participants knowledge about the natural resources within Hacienda Esperanza.

Simultaneously, while the CPTR made these observations, the Center for the Advancement for Informal Science Education (CAISE) released the findings on the 3 models for public participation in scientific research: 1) contributory, 2) collaborator and 3) co-creator models, based on the degree of engagement of the participant with the scientific enquiry process (Bonney et al, 2009). Contributory projects are research driven data collection projects where the scientist trains participants at contributory phase to collect scientific data over long periods of time over wide geographical ranges. This has been the level of engagement traditionally used to engage citizens in collection of scientific data. Training was provided for a short period before the citizens were left on their own to collected data. There was little or no interactions between scientists and citizens except for handing in data sheets or data entry into a website (Bonney et al, 2009). Collaborative model's scientist still asks the research question however citizens participate in data analysis, interpreting data and presenting results to other members of the public or scientific community. In the co-creator model, members of the community come up with the research questions and remain with the scientist in all stages of the research process: from refining questions, developing methodology, to disseminating results and asking new questions.

These findings from previously project, stimulated the inquiry by the authors to asses and understand processes and pathways of educational approaches and pedagogic techniques used by scientists and the CTPR team to successfully engage citizens so that they passed through all three models of public engagement. The aim of this ISE research project, funded by NSF #1223882, was to authenticate the observations and findings of the first approach for citizen science used by CTPR (www.cuidadanocitifico.org/toolkits) in the context of 3 models of participant's engagement proposed by CAISE and to explore STEM-ISE pedagogy for Hispanic populations. Researchers were interested in evaluating the different components of the ISE approach and their interactions in the three model approaches proposed by CAISE (Bonney at al 2009) for successful citizen participation in science. The objective was to systematize ISE approach by observing the methods and practices used by staff of the CTPR to promote the development of citizen scientists for Hispanic audience within the 3 phases proposed by Bonney et al (2009). The specific research questions were to 1) Identify the profiles and roles of the different components within the educational model for the implementation of successful citizen science projects 2) How the pedagogy of scientific and educational activities in each of the five scientific research proposals promote the development of the general characteristics of the citizen scientists, as defined by the CTPR Project, and 3) What elements for citizen scientists must prevail in the learning and teaching processes within project experiences for participants to remain engaged in the 3 levels of citizen participation proposed by CAISE.

Methods

To evaluate the practices used in this ISE approach to citizen science multiple techniques were used to formalize and define the different participants and their roles within the ISE approach and to learn the commitment of scientists to further advance ISE experience. Like in the first ISE project, there were five science projects (Bats, Birds, Rivers, Coasts and Archaeology) where researchers developed science research projects to explore the impacts of urban development on natural and cultural resources along the Río Grande de Manatí watershed across 4 municipalities (Figure1). Each research project implemented scientific qualitative and quantitative methods to collect scientific data together with first time and repeat participants. Within conferences, workshops and field trips scientists encouraged participants to become active in project design, data collections, data analyses, interpretation and dissemination to the public and scientific community.

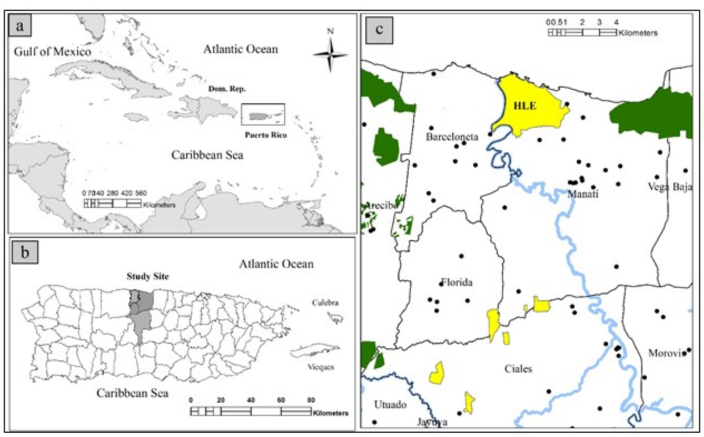

Figure 1: Map showing a) Location of Puerto Rico in the Caribbean, b) Study site in the northern coast of Puerto Rico c) Landscape of the Rio Grande of Manatí Watershed. Yellow polygons show natural protected areas managed by Para la Naturaleza (HLE is Hacienda La Esperanza). Green polygons showing state managed natural protected areas. Black dots represent schools within the watershed as an indicator of urban development.

To evaluate teaching practices adopted by the five scientists in this ISE project several tools from previous ISE projects were reviewed, including monthly and annual reports, scientific papers, tool kits describing scientific projects and administrative documents (n=7), videos and documentaries (n = 3), proposal of each scientific research project (n=5), and external evaluators report (n=3). To corroborate findings from documents reviewed the following assessments were completed: focus group meeting (n = 8), and individual structured and semi structure interviews (n = 9). To evaluate the teaching techniques and learning processes with ISE for Hispanic audiences the following was carried out: evaluations for the impact for the use of audiovisual materials in the field (n= 11), direct observations (n=29), and retro-informative meetings with scientists (n=6). The review of documents, audio visual materials and meetings allowed the evaluator to understand and define the roles of the various participants which allowed for a successful citizen science education program while engaging STEM learning in Hispanic audiences (Muniz, 2015).

Findings

The ISE used by the Trust for the citizen science projects that transforms citizens along the 3 phases trajectory proposed by CAISE has several components. Each component has specific roles and clear definition of function.

Roles and Hierarchy within ISE Project

The administrators (CTPR staff) form the highest tier of the approach as their role underpins the design, implementation and measurements of impacts within the project. The administrative staff at various levels within the organization is key as they play a vital role in decision making related to the Project including management of Budget, planning and coordinating with scientists research themes, frequency of citizen science activities, design and development of recruitment and retention strategies of citizen scientists, development and implementation of evaluation program, producing teaching and field material, developing and implementing dissemination plan for project results. To achieve the full engagement of all the component in this educational model, the coordination and interactions among consultants, staff from different divisions and scientists was dynamic, frequent and adaptable to the needs to the project.

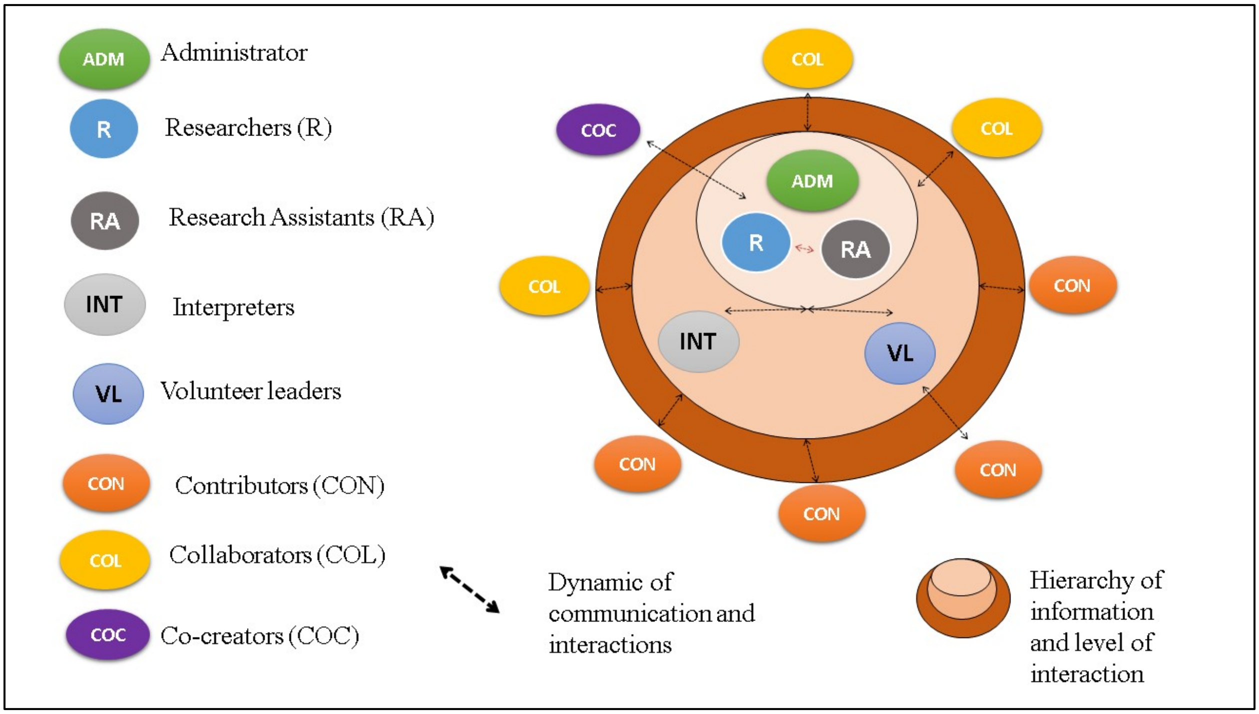

Figure 2: The hierarchal approach in a ISE model for Hispanic audiences

Following the administrators in the hierarchy is the "teaching group, the Researchers (R) and the Research Assistants (RA). The researchers were the principal components that adapted their research methods to include citizen science. They designed the research projects to investigate how urban development within the Rio Grande de Manatí impacted biodiversity and ecosystem functions and processes. The researchers provided explicit information to the participants on the specific research theme and the scientific methods they would use to collect data. They provided information using various formats from conferences on scientific methodology, workshops in how to use different equipment and how to enter data into the database. They were the key persons to provide instructions on how research methods were to be carried out, data collection and entry completed and development of teaching materials to fully engage participants. They were the leaders in the development of empathic conversations including language that was accessible to respond to questions of the participants about their research projects. Further they were responsible for the development and integration of various teaching materials such as videos, recorded sounds, stuffed models of birds and bats to describe morphology, make modifications to plans and research methods to meet the needs and interest of their participants. Scientists were asked to identify and mentor participants as they advanced within the 3 models of public engagement: from contributors to collaborators and from collaborators to co-creator's phases within this ISE project.

The research assistants (N=10) played a crucial role in the research Project implementation. They were individuals that had a high interest in the research project early on and worked in collaboration with the scientists to provide explanations and examples to participants, prepared all field or workshop materials for scientists, provided instructions to participants on data collection and entry, and established inclusive empathic conservations with participants. They provided participants copies of teaching materials such as field guides, posters and maps. Further they provided hands-on experiences with participants on the use equipment and materials. Assistants provided retro information to participants and scientists to ensure research methods were adhered to. They assisted in the modifications of research methods to ensure scientific rigor. Gradually, research assistants developed the skills equivalent to that of the scientist. On many occasions research assistants would substitute scientists in the fieldwork or data entry workshops. Their observed dominance of the research theme created an environment of peer to peer mentoring and learning with participants. They also helped scientists identify participants that showed interest in the project and encouraged them to become collaborators and co-creators.

Interpreters (I) and volunteer leaders were part of the support staff designated to the field component of the ISE Project. The principal role of the interpreters in the project included an introduction and a brief of what to expect on each activity. They provided participants with relevant Internal Review Board (IRB) documentation approved by the Inter American University of Puerto Rico (#12-13-001), explaining that this was part of a larger research project on informal sciences education for Hispanic audiences. They coordinated the logistics for the field trips from transportation, packing of materials and equipment required for the field trip, identification of possible collaborators and co-creators, and provided motivation to participants in the field. Their role also was to stimulate effective dialogue among participants and scientists ensuring instructions were communicated clearly and explicitly to participants in a language that was non-technical and understandable by the public.

In this ISE model participants interacted with the core "teaching" group at different levels and times along this hierarchy. There were three types of participants (1) one-time participants were at the contributory phase of ISE model (CON). Here one-time participants actively contributed to data collection in the field, 2) Collaborator (COL) phase where participants were involved in data collection and entry, and dissemination of findings at community meetings. Co-creator (COC) participants collected and entered data, disseminated results in communities and in scientific symposiums and developed their own community citizen science projects. Participants' role is defined depending on the type of activity they were involved in. In a classroom setting for conferences or workshops they were passive listeners with occasional questions and note taking. In the field, component participants were active in data collection and entry with use of equipment and materials while working in groups, the collaborators and co-creators with field methods experiences intervened and mentored new participants by re-explaining the activities for the day and showing the use of equipment. The core creator's participants interest to develop a community-based citizen science project included divulging information about the project to friends, family and community.

Pathways and Processes in Approach to ISE for Hispanic Audiences

The first phase of the ISE project was to meet with partners to develop scientific research projects that would not only collect data over large geographic and temporal scales but also engage citizens in all levels of citizen science models (contributor, collaborator and co-creator) (Figure 3, see process 1). Five research projects were developed in birds and plants, archaeology, rivers, beach, and bats. The CTPR administration team together with external evaluators review scientist's proposals, time table of work and selection of study sites to ensure the creation of opportunities for citizen engagement in data collection, analysis and dissemination (Figure 3, see process 2). The CTPR administration team together with researcher implemented and adjusted all field methodologies, workshops, and laboratory methods to ensure logistics and proper functioning of equipment. Prior to field seasons, the Inter Review Board (IRB # 12-13-001) process was completed and all relevant permits for working with plants and animals were obtained for each research project. Also, all field equipment, teaching kits, tools, evaluation and data collection materials was prepared and transported to study sites by CTPR staff and volunteer leaders. The CTPR logistics team ensured evaluation instruments were administered and stored per IRB procedure. Evaluation tools were developed with scientist to determine changes in knowledge, skills, attitude and behavior of participants (Figure 3 see process 3). The CTPR team met frequently with evaluators, researchers and research assistants to trouble shoot and clarify objectives of the ISE research, the processes involved in evaluation and the presentation of the ISE approach developed from the five case studies (Figure 3, process 4). Further, the administrative teams kept track of one time and repeat participants while the researchers through different teach techniques provided opportunities for contributors to convert to collaborators and collaborators to co-creators. Once researcher evaluated knowledge and skills of collaborators and co-creators they helped participants develop research proposal for their community-based citizen science projects (Figure 3, see process 5). During a period of two years from 2012 to 2015 scientist's collected, analyzed and disseminated data about their research project while fully engaging citizens thus allowing them to strengthen their research and communication skills to a level where they could develop their own community based citizen science project (Figure 3, see process 6).The CTPR administration teams reviewed and revised all proposals to ensure they were within the scope of funding, purchased equipment and materials and developed a calendar of activities for citizen scientists. In collaboration with researchers' workshops on data entry and analysis was offered to co-creator citizen scientists. Also, the CTPR administration team developed a calendar of community outreach activities that allowed citizen scientists to dissemination information about their project and recruit members of their community to volunteer in data collection, entry and dissemination (www.cuidadanocientifico.org)

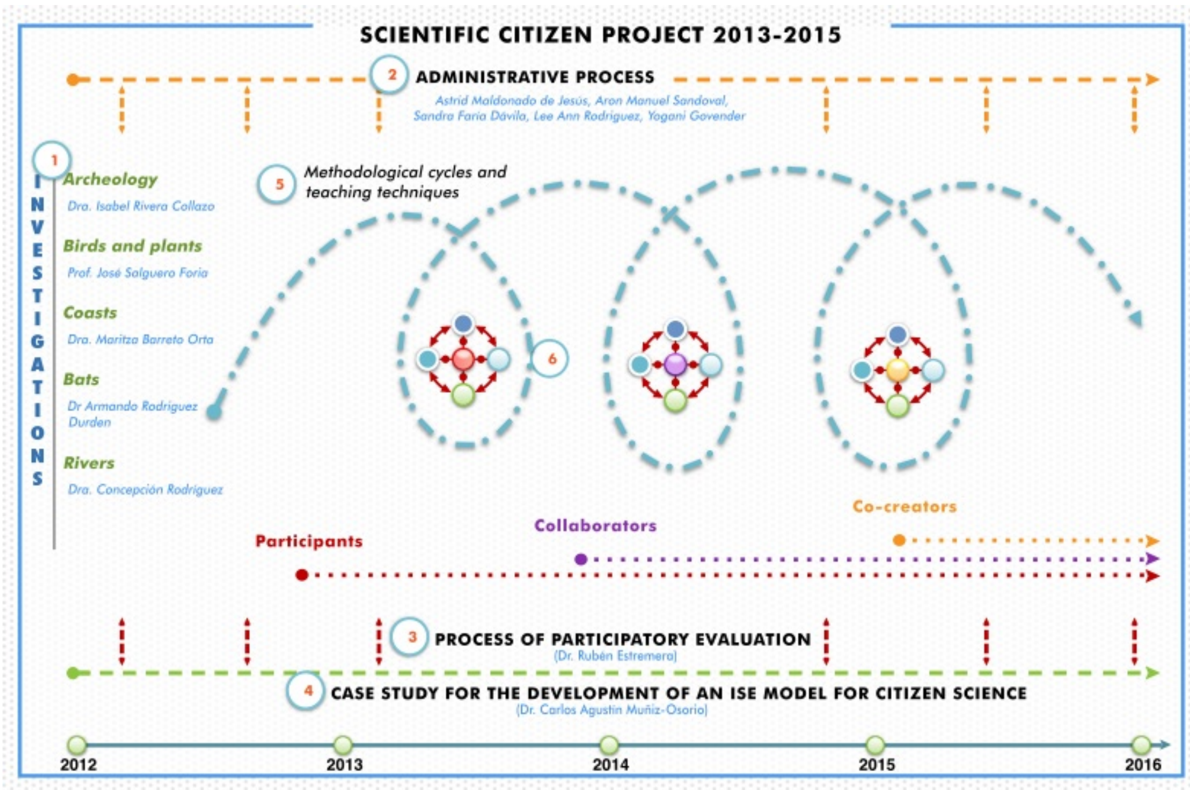

Figure 3: Pathways and Processes in ISE approach used for Hispanic Audiences (adapted from Muniz, 2015)

The Pedagogy of Informal Science Education for Hispanic audiences

For this informal science education (ISE) project there was a strong evaluation process that allowed researchers to determine the level of change in knowledge, skills, attitudes and behavior of participants. First, participants were requested to complete consent form to participate in the evaluation as per IRB and to sign a waiver form to participate in scientific activities. Participants were given pre-and post-questionnaires to determine their knowledge gain on specific scientific research project. Therefore, at the beginning and end of each activity in all research projects there was a component of administration and documentation.

Teaching Styles and Techniques

Across all scientific projects researchers incorporated distinct teaching strategies when compared to teaching in the classroom (Figure 4). Activities for this ISE included workshops, field trips and laboratory work. Initially, some research projects used introductory workshops and conferences to provide all participants background information about the research theme. The workshops also provided details on the methods and the proper use of materials and equipment in the field. However, early on, scientists realized that introductory workshops were not effective, as participants that attended the workshop did not necessarily attend the field trips. Therefore, this component was cancelled in the project calendar, and it was decided to train participants in the field during the introduction phase. After six months, the scientists and CTPR staff developed demonstration workshops that were organized to teach collaborator participants the use of Geographic Positioning Systems (GPS), Geographic Information Systems (GIS) and the use of Excel for data entry in the data base at www.cuidandocientifico.org.

Fieldwork is an effective technique in engaging citizens in science. All research projects had a field component for data collection. The activities in the field followed the same order of implementation for all research projects. Initially the teaching team (R & RA) and interpreters (INT) provided a brief introduction into citizen science, the objectives of the ISE project and provided participants with relevant documentation (Waiver forms, pre -tests with IRB permits). This introduction was followed by interpreters providing participants with relevant security information. Field security measures were different according to each research theme; for example, in the river and beach projects participants were required to use life jackets; in the bats projects participants were made aware of the risk to rabies should they get bitten, and in the case of the archaeology and birds project general information in case of an emergency was revised.

Then researchers and assistants provided specific information about the research theme, explained the scientific methodologies, and the use of equipment to be used in data collection. The teaching staff (R & RA) used demonstration teaching techniques to train participants on the use of equipment. To ensure maximum engagement of all participants a buddy system was developed where repeat participants were given" leadership" roles to orientate and teach first time participants the use of equipment and implementation of specific scientific methods for that research project. In the field, audio-visual aids were effective in informing the public about the specific research projects. such as informative brochures, maps of the study area, audiovisuals, guides, written information on methods to be used, photographs, methods on how to use specialized equipment such as GPS, sensors, specialized programs for data collection and data entry as well as life like models of bats and birds to show anatomy of organisms. Through question and answer sessions the teaching team ascertained the physical and scientific knowledge capabilities of participants. Scientists used this teaching style to adjust the level of their technical language to the level of their participants and to divide the workload among the group.

Planned recess was organized after 2 hours of data collection, with snacks and drinks, to allow researcher to review work completed and correct any errors in data collection. This period facilitated informal conversation, both among participants and with the teaching group (R & RA) and mentors (INT & VL). The final stage of the fieldwork was a closing session where participants were given the post-test and the researchers discussed the day's findings and gave thanks to all participants.

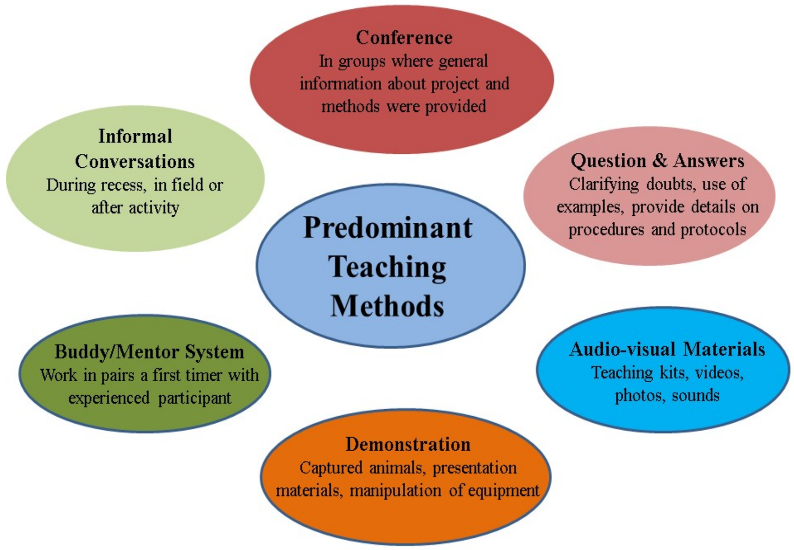

Figure 4: Different predominant teaching strategies used in Informal Science Education (ISE) for Hispanic audiences

Discussion

The emergent model determines that the role individual components of the teaching staff which includes Trust staff, scientists/researchers, research assistants and volunteer leaders (teachers) is the epicenter of this ISE model (Figure 2). The division yet interlaced processes of tasks by teacher in the model is what makes ISE within the Rio Grande de Manatí successful. While teacher has a specific role the effective communication in the planning and implementation phase allows any one of these teachers to substitute each other during the field component of the project. The close interactions among the teaching staff and the clear study goals of engaging participants in all steps of the scientific process allows participants an experience that facilitates gain in knowledge and skills with changes in attitudes and behavior towards science, nature and conservation.

The effective ISE model for engaging citizens in science through the 3 phases of contributory, collaborator, and co-creators involves several actors with varying degrees of interactions. These include teaching staff made up of the Trust staff, scientists/researchers, research assistants and volunteer leaders (teachers). Each component plays a specific role within the model, however, in the case of this ISE model the roles by the different components were easily interchangeable. For example, when the scientist (R) is absent the research assistants, interpreters, or co-creators are confident with the knowledge and skills to receive citizens who participate in the field trips and in data collection. The interchangeability of roles allowed the teaching-learning processes to be democratic, with open dialogues and informal discussions. The fundamental educational methodological principles used in the ISE model included: inquiry methods through questions and answers, working with peers, direct interaction with equipment and materials, field trips, workshops and laboratory integration for understanding and learning scientific process and research.

This form of multimedia learning was found to be highly effective. Mayer (2008) found that by combining words and pictures as opposed to presenting information by words alone, produced in students effective long-term learning. The instructional methods used in the ISE project, in all research projects, adopted this multimedia technique ensuring effective transformation of participants from contributors, to collaborators, all the way towards co-creators. The success of teaching techniques used is further evidenced by the methodologies adopted by participants in their community-based science projects. Of the 14 projects developed

13 used the same or similar teaching and scientific methodologies used by their research mentors.

Conclusion

The findings of the impacts of the ISE for gain of STEM knowledge provides new information for k-16 education. ISE is can be used for the integration of STEM disciplines because of its transverse nature that integrates experimental research in both natural and social sciences, develops collaborative learning, and collective organization in the process of learning through multiple components in the model.

The model emphasizes the hierarchy of the different components that allow for the integration of various teaching techniques concurrently with hands-on experiences. Further, the ISE model developed in this project shows that although the pedagogic processes of teaching and learning occurred in an informal setting, there is an important administrative role in planning. Like others, Bonney et al (2009), Miller-Rushing, Primack and Bonney (2012) and Sachs, Super & Prysby (2008), we conclude that the combination of the citizen science project team with clear and concise educational goals in a structured citizen science framework is a powerful tool to obtain meaningful, useful, and relevant scientific data to address real-life ecological and environmental problems.

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