Using the Science of Hurricane Resilience to Foster the Development of Student Understanding and Appreciation for Science in Puerto Rico

Steven McGee, The Learning Partnership
Randi McGee-Tekula, The Learning Partnership
Noelia Baez Rodriguez, University of Puerto Rico

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Abstract

For school age children on the island of Puerto Rico, the back-to-back hurricane strikes of Irma and Maria were their first experience with the tragedy of hurricanes in Puerto Rico. There is much concern in the general public about the ability of the Puerto Rican forests, like El Yunque, to recover. These concerns reveal common misconceptions about the dynamics of forest ecosystems. The focus of this research is *Journey to El Yunque,* a middle school curriculum unit that engages students in evidence-based modeling of hurricane disturbance using long-term data about population dynamics after Hurricane Hugo. Research was guided by the following research question: *How does engagement in the science of disturbance ecology impact students' understanding of and appreciation for ecosystems dynamics?* Students completed pre and post assessment understanding of ecosystems dynamics and rated the teacher implementation using the Inquiry-Based Science Teaching survey. Based on a paired t-test, students statistically increased their performance from pretest to posttest with an effect size of 0.22. At the teacher level, the Inquiry-Based Instruction score was a statistically significant predictor of the posttest performance. In other words, these results provide evidence that engaging students in the practices of ecology predicted increased understanding of population dynamics.

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1 Overview

On September 20, 2017, Hurricane Maria made landfall on the island of Puerto Rico as a Category 4 Hurricane with sustained winds greater than 133 mph. The entire electric grid was destroyed and most of the island was without power for 11 months. Residents were also left scrounging for water from fresh streams. For school age children on the island of Puerto Rico, the back-to-back hurricane strikes of Irma and Maria were their first experience with the tragedy of hurricanes in Puerto Rico. They were not born when Hurricane Georges struck the island in 1998. For many adults on the island, the experience of Hurricane María seems worse than previous hurricanes such as Georges (1998) or Hugo (1989). Due to the strained financial situation in Puerto Rico, many have expressed concerns about the extent to which the island will be able to recover at all from Hurricane Maria (Resnick & Barclay, 2017). As expressed by a New York Times article almost a month after Hurricane María, there was also much concern in the media about the ability of the Puerto Rican forests, like El Yunque, to recover (Ferré-Sadurní, 2017). These concerns were echoed in the reader comments associated with the article. One reader, with the username of Fritz, commented that they had visited El Yunque as an undergraduate in the year 2000 and described the experience as "otherworldly." In referring to the cover photo showing the damage from Hurricane María, Fritz lamented that, "*This is the part of Puerto Rico that may not recover in my lifetime.*" It seems that Fritz was unaware that two years before their 2000 visit, El Yunque had been struck by Hurricane Georges in 1998 (Figure 1). By the time of her visit in 2000, the rainforest was well on the way to recovery (Figure 2). Fritz's comments and others reveal common misconceptions about the dynamics of forest ecosystems. Seeing pictures of stripped and fallen trees, where once was luscious green forest, can lead many to believe that the forest is dead.

Long-term ecological research paints a different picture about the dynamics of ecosystems in the face of disturbances like hurricanes. The National Science Foundation funds a network of 28 Long-Term Ecological Research (LTER) sites across North America, the Pacific Ocean, and

Figure 1: Photo along Big Tree Trail in November 1998. Photo by S. McGee.

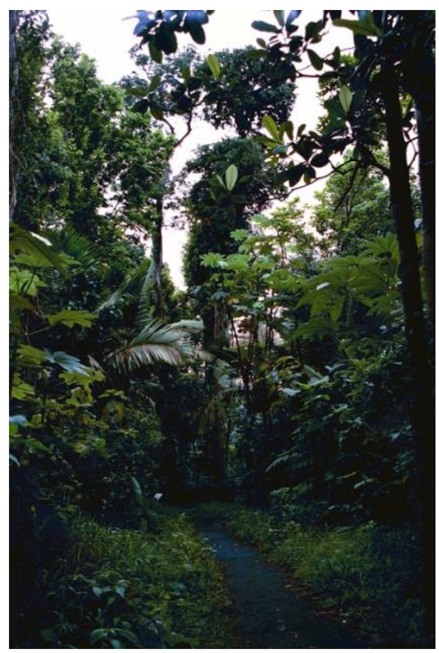

Figure 2: Photo along Big Tree Trail in September 2000. Photo by S. Croft. Used with permission.

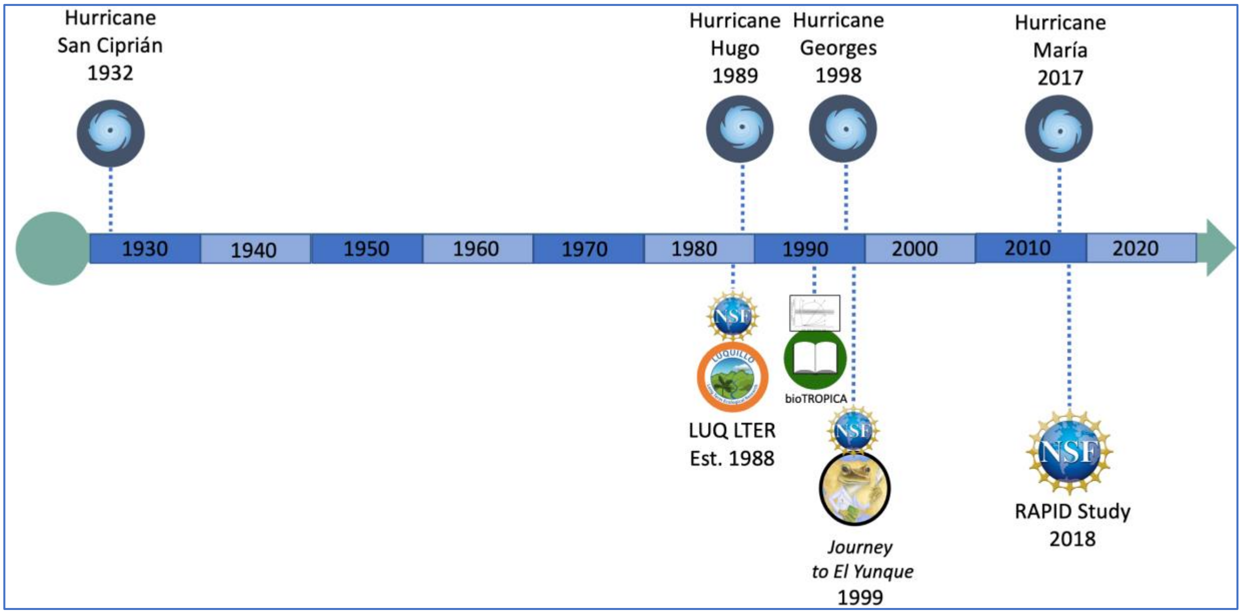

Figure 3: Timeline of disturbance evens as well as LUQ LTER science and outreach

Antarctica. "*The LTER Network was founded in 1980 by the National Science Foundation with the recognition that long-term research could help unravel the principles and processes of ecological science, which frequently involves long-lived species, legacy influences, and rare events."* (LTER Network Office, 2022) The Luquillo LTER (LUQ) site is located on the island Puerto Rico. Founded in 1988, their research is focused on the dynamics of the El Yunque rainforest in the face of hurricane disturbance. The rainforest is adapted to being struck by hurricanes on a regular basis. There are a variety of species whose niche is the bright sunlight and abundant debris conditions that exist after a hurricane. These species keep precious nutrients in the forest and form the foundation for the mature forest species to recover. Understanding these dynamics of complex systems is essential for scientific decision making (Jaconson & Wilensky, 2006). Yet, complex systems are not generally taught in school, which has negative consequences for students' ability to understand what happens when complex systems are impacted by disturbances (Liu & Hmelo-Silver, 2009).

To address misconceptions about the resilience of the rainforest to hurricanes, it is helpful to set hurricane disturbance and long-term ecological research and outreach in Puerto Rico in historical context (Figure 3). There was a 57-year span between Hurricane San Ciprián in 1932 and Hurricane Hugo in 1989. That time span between hurricanes is typical of the average hurricane interval over the last millennia—about every 50-60 years. However, in the last 30 years, El Yunque has been struck by Hurricane Georges (1998) and most recently Hurricane Maria (2017). Is this increase in hurricane frequency an anomaly or is it a trend? If it is a trend, how might that affect the

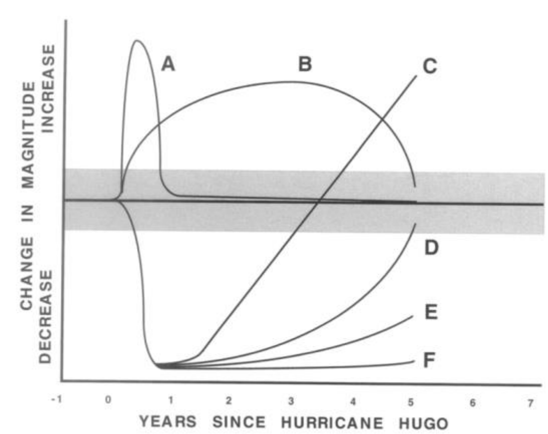

Figure 4: Idealized 5-year trajectories of responses of different components of El Yunque to Hurricane Hugo. Reprinted from "Introduction: Disturbance and Caribbean Ecosystems," by J. K. Zimmerman, M. R. Willig, L. R. Walker, and W. L. Silver, 1996, Biotropica, 28(4), p. 417. Copyright 1996 by the Association for

rainforest? These are some of the questions that LUQ set out to investigate. Fortuitously LUQ was established one year before Hurricane Hugo, setting up Luquillo ecologists to study the effects the hurricane. The resulting research on resilience after Hurricane Hugo was groundbreaking. In 1996, the Luquillo ecologists published a whole *Biotropica* special issue on their research (Zimmerman et al., 1996). An important finding was the identification of characteristic responses to hurricane disturbance (Figure 4).

Shortly after Hurricane Georges, our team entered the scene. We started the *Journey to El Yunque* (elyunque.net) project in conjunction with the lead ecologist, Jess Zimmerman. Our goal is to engage middle school students in the Luquillo science of hurricane resilience using LUQ research on Hurricane Hugo as the context. Almost 20 years later in 2018, we received funding from NSF to help middle schools with their science programs in the aftermath of Hurricane Maria. We sought to use the context of research on El Yunque to help students explore the impact of hurricanes like the one they had just experienced. Our research was guided by the following research questions:

> *How does engagement in the science of disturbance ecology impact students' understanding of and appreciation for ecosystems dynamics?*

2 *Journey to El Yunque*

Journey to El Yunque aims to improve middle school students' understanding of the dynamics of disturbance and recovery after severe hurricanes. The program exposes students to the authentic research practices of ecologists. The research surrounding the recovery of species after these disturbances provides a rich example of basic ecosystem processes at work. In the program, students learn about the historical patterns of hurricane frequency and damage in El Yunque and investigate what happens to the producers and consumers in El Yunque after Hurricane Hugo. The overarching question students investigate is the same as one of the primary research questions that Luquillo ecologists are investigating (Figure 5): *"Organisms in El Yunque seem to be well adapted to hurricanes, but what will happen to the ecosystem if severe hurricanes strike the rainforest more frequently?"*

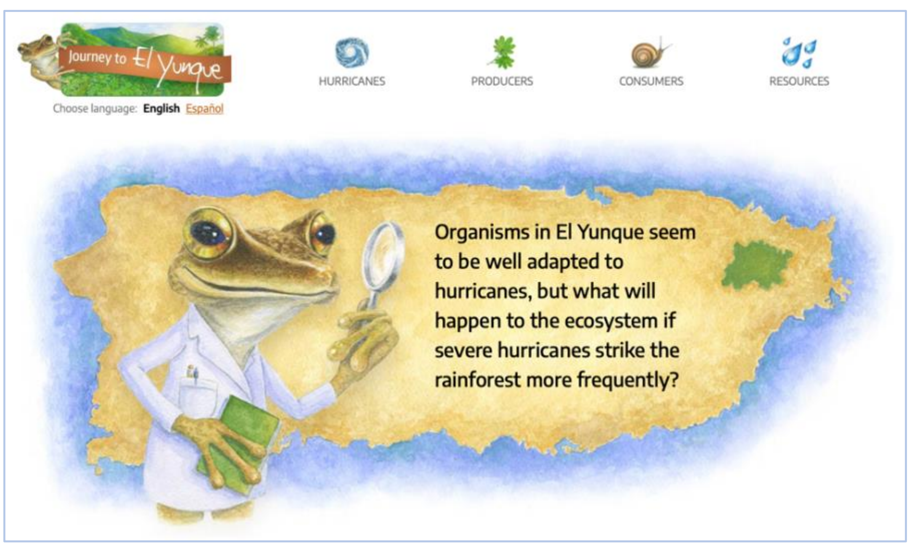

Figure 5: Journey to El Yunque home page (elyunque.net)

The program introduces students to five consumer species that are representative of the types of hurricane responses that ecologists have found in El Yunque (Figure 4, Zimmerman et al., 1996). There are two decomposers (mushrooms and snails), one primary consumer (caterpillars), and two secondary consumers (anole and coquí). As part of the investigation, students read about the life history of their assigned consumer, make a prediction about the population dynamics after Hurricane Hugo, and explore a model of population dynamics to explain what happened to their species after Hurricane Hugo.

When investigating population dynamics after a disturbance, scientists in El Yunque typically consider changes to four primary limiting factors for a given species: access to prey, avoidance of predators, direct mortality from the hurricane, and suitability to changes in environmental conditions, in particular the openness of the forest canopy and the influx of forest debris from the hurricane. Each species has a series background readings focused on providing the life history of each limiting factor. The readings highlight key vocabulary in the context of the El Yunque ecosystem. They are written at a 5th grade reading level in English and Spanish. While the students are reading, they are provided with a notetaking template that provides boxes for students to take notes on what they learn about the life history of the species related to each of the limiting factors.

After completing the background readings, students are asked to predict the graph of the population of the species over the 5-year period following Hurricane Hugo. Students are presented with a blank graph. Using the mouse, students click and drag within the graph to draw a blue line representing their prediction about the population levels of their target species in each month for 60 months. On their worksheet, students use scientific concepts from their reading notes to provide a justification for their prediction. After writing their justification, they click on Test Prediction to see a green line graph of the interpolated population data that was collected by scientists after Hurricane Hugo. Students are given the opportunity to generate hypotheses about the factors that may explain the graph of the population.

To support students in exploring the factors that affect population dynamics, we developed computational models for each of the species using the Stella modeling software (Easley et al., in press). We started the development each model by identifying a basic ecological model in Hannon and Ruth (1999) that had similar characteristics to the targeted species. We then synthesized the relevant ecological literature about the target species to develop estimates of the parameters related to the limiting factors. For example, the anole lizard is one of the secondary consumers that

(a) (b)

Figure 6: Screenshots of the process of modeling population data. (a) The student has run the model without changing any of the input parameters. (b) The student has increased the availability of prey and has drawn the canopy to reflect the total loss of canopy after the hurricane and gradual return over a 5-year period.

students can investigate. The loss of tree canopy after Hurricane Hugo created competition for the ground dwelling anole (*A. gundlachi*) as the canopy dwelling anole (*A. stratulus*) were forced to live on the forest floor. As the canopy recovered, the *A. stratulus* were able to return to the canopy thus reducing competition. In addition, the increase in ground cover flowers and shrubs from the increased exposure to direct sunlight brought an increase in the availability of insects, which are a primary food source for the anole. These factors were built into the model. The underlying mathematical equations that Stella generates were ported to an authoring environment to develop the graphical interface for students to manipulate select parameters (Figure 6).

Figure 6 shows screenshots of the process of modeling. The first image (a) shows a model run using the default parameters. The blue model output line remains stable and does not provide an approximation of the population dynamics after a hurricane, represented by the green line. In the second image (b), the student altered the canopy parameter to simulate the complete loss of canopy and the gradual recovery. In addition, the student increased the input of prey to the system. The model output comes close to approximating the actual data. Students are expected to use the scientific language from their background reading notes and the evidence from the model to develop a scientific argument about the factors that might explain the dynamics of the anole population after a hurricane.

3 Legitimate Peripheral Participation

Our goal with *Journey to El Yunque* is to engage students in LUQ science as junior members of the community. Lave and Wenger's (1991) Legitimate Peripheral Participation framework provides the framing for how we engage students as junior community members. Lave and Wenger argue that all learning is a form of legitimate peripheral participation in the context of communities of practice. The question becomes to which communities are students positioned as legitimate peripheral participants. In contrast to their analysis of apprenticeship practices across multiple contexts, Lave and Wenger highlight the inherent conflict that exists in school settings that are structured around teaching practices. The content of school instruction emerges from specific communities of practice; however, students are rarely positioned as legitimate peripheral participants with reference to those communities where the content of instruction emerged. Instead, students are often positioned as legitimate peripheral participants with reference to the community of educated adults. Lave and Wenger's legitimate peripheral participation framework provides a lens by which to examine and structure how we can provide students with opportunities to be positioned as legitimate peripheral participants with respect to the scientific community. There are several key characteristics of the framework that can be embedded in school contexts to engage students as legitimate peripheral participants (Table 1). The first three characteristics focus on the legitimacy of student participation in the community. The last two characteristics focus on the peripherality of student participation in the community.

Table 1: Key Characteristics of Legitimate Peripheral Participation

Legitimate Peripheral Participation Key Characteristics	
Characteristics related to *Legitimate* Participation	1. Scientific Practices 2. Scientific Tools 3. Learning the Language
Characteristics related to *Peripheral* Participation	4. Learning Sequence 5. Identity Development

(a) Scientific Practices

To be considered legitimate peripheral participants, some people may think that it is necessary for students to be contributing to the scientific community through activities such as citizen science. However, Lave and Wenger (1991) argue that being positioned as a legitimate peripheral participant depends largely on the extent to which students are engaged in the scientific practices of the community. "…*opportunities for learning are, more often than not, given structure by work practices instead of by strongly asymmetrical master-apprentice relations*." (p.93)

(b) **Scientific Tools**

As legitimate peripheral participants, students learn to use the scientific tools of the community. Lave and Wenger (1991) use the term *transparency* to characterize this learning process. "…*the term transparency when used here in connection with technology refers to the way in which using artifacts and understanding their significance interact to become one learning process*." (pp. 102-103) Lave and Wenger use the metaphor of a window to exemplify how transparency involves both invisibility and visibility. The window is invisible in that it provides visibility to what is outside of the room. The salient phenomenon is the subject matter that the window reveals. The wall on the other hand is visible and salient and does not reveal the subject matter of interest, namely what is outside the room. Scientific tools move from a position of visibility and salience to a position of invisibility, thus making salient the phenomena of interest to the community.

(c) **Learning the Language**

Becoming a member of a community is more than just an increasing ability to engage in the tasks. It is also dependent on building social bonds with other members of the community. "*For newcomers then the purpose is not to learn from talk as a substitute for legitimate peripheral participation; it is to learn to talk as a key to legitimate peripheral participation*." (pp. 109-110) Communication is key to developing bonds around the goals of the community as well as sharing what is learned from practice. It is essential for newcomers to be able to use the language of the community.

(d) **Learning Sequence**

At the outset of learning, students are not able to successfully engage in all aspects of scientific practice. "*A newcomer's tasks are short and simple, the costs of errors are small, [and] … tend to be positioned at the ends of branches of work processes, rather than in the middle of linked work segments. (p110)* "*Production activity-segments must be learned in different sequences than those in which a production process commonly unfolds*…" (p.96) Within the context of an apprenticeship approach, students will experience the entire process of an investigation, but focus on completing specific steps independently. For example, given a specific research question, a set of data related to the research question, and graphs displaying patterns in the data, students may focus on interpreting the graphs to provide evidence for an answer to the research question. As they develop facility with interpreting graphs, they may begin to take on generating graphs in subsequent investigations.

(e) **Identity Development**

Lastly and most importantly, Lave and Wenger characterize learning as movement from the periphery of a community to becoming a central member of the community. "…*a deeper sense of the value of participation to the community and the learner lies in <u>becoming</u> part of the community…Moving toward full participation in practice involves not just a greater commitment of time, intensified effort, more and broader responsibilities within the community, and more difficult and risky tasks, but, more significantly, an increasing sense of* *identity as a master practitioner. (pp. 111-112)* The process of identifying with a community of practice is double-sided (Stevens et al., 2008). On the one side, as students develop a commitment to the goals of the community and are successful in the small tasks they are given, they build a connection with the community and a desire to take on more responsibility. On the other side, members of the community must recognize the success of learners and confer additional responsibility. It is imperative to support the development of student identity as a member of the community.

In the case of *Journey to El Yunque,* students engage in the *scientific practices* of Luquillo ecologists. They investigate the same research questions that Luquillo scientists are investigating. Students focus on analyzing long-term ecological data to develop explanations of population dynamics in the context of hurricane disturbance. Students use models of population dynamics developed by Jess Zimmerman as a *scientific tool*. To maximize the transparency of the modeling tools for students, who likely have little experience using modeling tools, the graphical interface allows students to set the starting conditions of the models based on their hypotheses about how those factors changed after a hurricane. Thus, the modeling tool can serve as a *window* to the phenomenon of population dynamics. The background readings create opportunities for students to *learn the language* of Luquillo ecology and then use that language as they develop their final argument. These first three characteristics position students as legitimate participants in the practice of Luquillo ecology. However, students are at the periphery of the community. They are not contributing to Luquillo science. *Journey to El Yunque* provides students with the investigation question, the data, and the models. Students focus on using the models as evidence to develop an argument about the factors that affect population dynamics after a hurricane. By focusing on the last step in the process of inquiry, we are initiating a *learning sequence*. In subsequent investigations, students would be prepared to independently complete other steps in the inquiry process, such as building their own models. Our prior research has shown that the context of serving as junior members of the Luquillo community does support student *identity development* as ecologists (McGee et al., 2018). As Dewey suggests (2016), student identification with the important questions of Luquillo science supports the development of an identify with the community and movement toward fuller participation as students develop their ability to use the language and scientific practices of the community.

4 Method

4.1 Population

During 2018-19 school year, twenty-two teachers in Puerto Rico participated in an introductory one-day workshop in September 2018. The teachers were provided with the opportunity to experience *Journey to El Yunque* as students and then reflect on how they would implement the program with their students. At the end of the workshop, the facilitators explained the study and invited teachers to assist with collecting student data during implementation. Ten of those teachers completed the implementation of the program with 183 students. Over 90% of the students were Puerto Rican. Two-thirds of the students were female. Our gender data is consistent with a persistent cultural issue in Puerto Rico in that boys are dropping as early as middle school to begin working and supporting the family (CB en Español, 2021). During the implementation, local science support specialists were available to answer questions and visit schools.

4.2 Instruments

There are two sources of evidence for our research question on engaging students in the science of ecosystems disturbance correlating with student understanding of ecosystem dynamics. First, we assessed students' pre and post understanding of ecosystems dynamics. We used a collection of state standardized ecology assessment items focused on ecosystem dynamics. These items have been used in previous research with the curriculum (McGee et al., 2018). The assessment included 8 multiple choice assessment questions related to population dynamics. There was one constructed response question in which students analyzed the relationship between lynx and hare in a tundra environment. During the Rasch modeling process, it was determined that one item did not fit the Rasch model well. It was an item that required students to have the background knowledge that foxes were predators to squirrels. However, foxes and squirrels are not tropical animals and students in Puerto Rico would not likely have background knowledge of those animals. Therefore, the item was dropped from analysis. In the future, the item will be modified to include a food chain to enable students with no knowledge of those animals to still be able to reason about data to interpret population dynamics. The resulting Rasch scores were scaled to range from 0 - 10.

The multiple-choice items fell into two clusters based on the level of difficulty. The first cluster of 4 items ranged in difficulty from 0 to 3.9 on the 10-point scale. The items asked students to explain the change in a population based on changes in the animal's prey or predator populations. For example, given a food chain of wheat, mouse, and hawk, a decrease in the hawk population would lead to an increase in the mouse population. These items were generally easier than the second cluster of items. There were three multiple choice items in the more difficult cluster. They ranged in difficulty from 3.9 to 10. These items required students to account for more complex factors influencing populations. One requires students to consider the effects of population changes on the environment. One requires students to consider the effect of environmental changes on populations. The third requires students to reason about indirect effects in a food web. The constructed response question was significantly more difficult than the multiple-choice questions. The same set of questions were administered at pretest and posttest. The posttest items were anchored on the pretest item difficulties.

On the posttest exam, we collected students' ratings of teacher implementation of scientific practices using the Inquiry-Based Science Teaching survey. These survey items were adapted from an index used by Allensworth, Correa, and Ponisciak (2008). The surveys were administered on the posttest. Rating teaching through student surveys has been used successfully in prior research. Ferguson and Danielson (2014) found that student ratings of teaching were highly correlated with observational ratings of teaching by expert observers. In addition, this index of Inquiry-Based Science Instruction is correlated with performance on the ACT college entrance exam (Allensworth et al., 2008) and outcomes on a physical science assessment (McGee et al., 2017). The specific inquiry-based activities used in the survey include: (a) use laboratory equipment, (b) write lab reports, (c) generate hypotheses, (d) use evidence to support an explanation or argument, and (e) find information from graphs and tables, (f) use a model as evidence for an explanation or argument, and (g) create your own graphs. The answer options included: Not at all (1), Once or twice during the semester (2), Once or twice per month (3), Once or twice per week (4), and Almost every day (5). For each student, the items were averaged to create an overall score of science inquiry-based instruction for each student. For each teacher, the scores provided by the students were averaged to create a teacher-level inquiry-based science instruction score.

4.3 Analyses

We hypothesize that the extent to which teachers engaged students in the practices of science as measured by the Index of Inquiry-Based Science will correlate with increased understanding of the dynamics of ecosystem resilience. We first examined changes from pretest to posttest. The average pretest score was 4.5 out of 10 (see Figure 7). Since the average pretest performance is above the difficulty of the basic ecosystem questions, most students started the unit prepared to reason about complex ecosystem relationships like those found in *Journey to El Yunque.* We used a paired t-test to examine the change in performance from pretest to posttest. Students showed a statistically significant increase in their performance from pretest (4.5/10) to posttest (4.9/10) with an effect size of 0.22 (t=2.54, p<0.01).

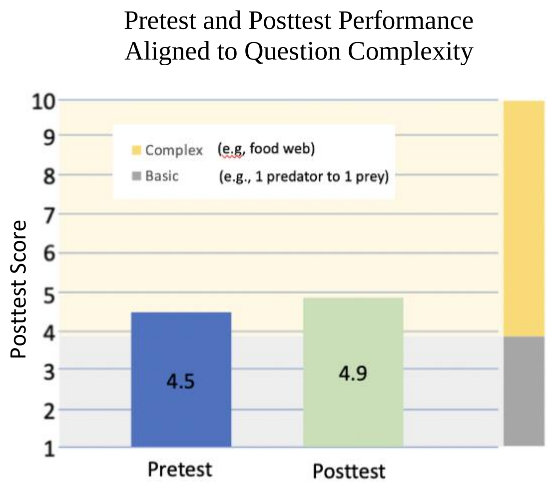

Figure 7: Bar Chart of Pretest and Posttest Scores with Reference to Question Complexity

Since teachers have multiple students, we used multilevel measurement modeling to develop an index of the posttest scores for each teacher that aggregates posttest scores from multiple students by teacher (Kamata, Bauer, & Miyazaki, 2008). We conducted the multilevel measurement modeling using *WHLM* software version 7.24q with student demographic and pre assessment scores at level 1 and the aggregate Inquiry-Based Science Instruction Score at level 2 for each teacher (Table 2). At the student level, after controlling for pretest performance, there was no difference in performance by gender. At the teacher level, the Inquiry-Based Instruction score was a statistically significantly correlated with posttest performance (Figure 8). In other words, these results provide evidence for the hypothesis that engaging students in the practices of Luquillo science is correlated with increased understanding of population dynamics.

Table 2: HLM Model results for posttest sore, by student and teacher characteristics. Coefficients and standard error are expressed as Rasch logits.

Characteristic	Coefficient	Standard Error	t-ratio	p-value
Average	-0.809	0.660	t(6) = -1.227	p = 0.266
Student Characteristics				
Pretest Score	**0.450**	**0.075**	**t(118) = 5.975**	**p < 0.001**
Female	0.109	0.239	t(118) = 0.456	p = 0.649
Teacher Characteristics				
Inquiry-Based Science Instruction	**1.857**	**0.720**	**t(6) = 2.578**	**p < 0.05**

Correlation Between Inquiry-Based Science Instruction and Posttest Performance

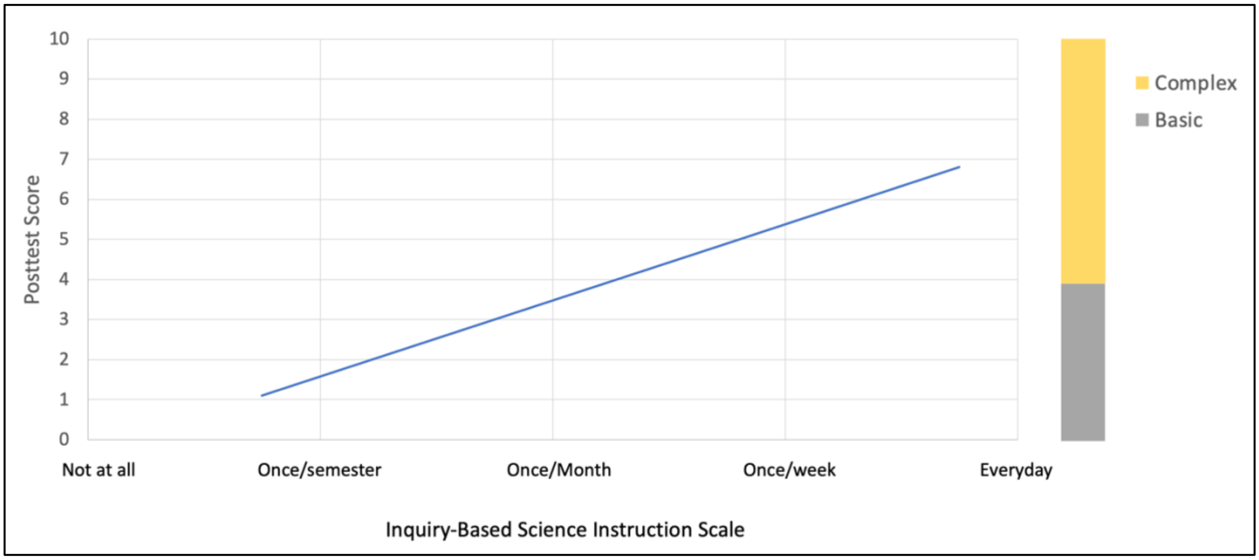

Figure 8: Graph of the Multilevel Model of Posttest Score by Inquiry-Based Science Instruction

5 Conclusion

Out of tragedy can emerge opportunity. Given the massive, long-term infrastructure recovery effort in Puerto Rico, there is a real danger of creating a lost generation of future Puerto Rican scientists, a group that is underrepresented in STEM (Meléndez-Ackerman & Colón, 2022). There is a real need to create pathways for elementary and secondary students to grow into the Puerto Rican scientific communities. Our results are consistent with Lave and Wenger's contention that all learning is enculturation into a community of practice. It is a matter of discerning which community students are being enculturated into. The focus of *Journey to El Yunque* is enculturating students into the Luquillo ecology community by engaging students in the practices of Luquillo science using the tools of Luquillo science and supporting the development of the language of Luquillo science. These are all elements that support the legitimate participation of students. We conclude with a return to the last two dimensions of Legitimate Peripheral Participation related to peripheral participation. As an indicator of identity development, we asked students on the post survey about the extent to which their participation in Journey to El Yunque increased their interest in pursuing ecology. More than half of the students said yes. In terms of learning sequences, many of the students had the opportunity in the 2nd semester to participate in our Data Jam project as a follow on from *Journey to El Yunque* (McGee & Rodriguez, 2017). Students took on greater responsibility for their investigations. They worked with raw long-term Luquillo ecological data to develop their own research question, analyzed the data, created graphical displays of the data, and developed an argument to address their investigation question.

The authors have a track record of providing students with authentic scientific experiences. Over the years, graduates of the program have become faculty members at universities in Puerto Rico and have gone on to successful STEM careers. This research provided an opportunity to investigate how engaging students in Luquillo science practices can help students understand and mitigate their own experience with hurricane tragedy, increase student understanding of hurricane disturbance and draw more students from underrepresented groups into the sciences, particularly those that have been turned off by traditional science. The results of our study provide evidence that engaging students as legitimate peripheral participants in the science of hurricane resilience fostered the development of student understanding and appreciation for science in Puerto Rico.

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