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TAKING STUDENTS ON A *JOURNEY TO EL YUNQUE*

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As the developers of *Journey to El Yunque*, we have taken a different approach to the process of designing a science curriculum. Rather than start with a specific set of concepts or skills to target as learning outcomes, we started by identifying a specific community of practice to which we sought to connect students. Researchers in the El Yunque rainforest in Puerto Rico have been studying the impact of hurricanes on ecosystem dynamics and have been modeling what the long-term impact would be if changes to the global climate increase the frequency of severe hurricanes. Therefore, hurricane impact became the focal phenomenon for the unit. We modeled the process of investigating hurricane impact after the long-term ecological research practices of researchers in El Yunque. Students begin by investigating the long-term impact of hurricanes on the producers in El Yunque. Next students investigate the long-term impact of hurricanes on various consumers in the rainforest. Finally, students investigate how hurricanes impact the cycling of resources directly as well as indirectly through changes in organisms' use of those resources in the rainforest. A central tension in the design process is how to coherently represent the spatial relationships between the components of the ecosystem and the temporal dynamics of the individual components. In this paper, we present the evolution of the program as we sought to balance that design tension and build an environment that connects students to the central phenomenon and practices of the community of researchers in El Yunque.

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Jess Zimmerman is a professor of ecology in the Department of Environmental Sciences at the University of Puerto Rico. He is the principal investigator for the Luquillo Long-Term Ecological Research program, upon which *Journey to El Yunque* is based. His current research interests are the impact of hurricanes and humans on the dynamics of tropical forest communities. Dr. Zimmerman received his doctorate in ecology from the University of Utah and his B.Sc. in biology from McGill University.

CONTEXT OF *JOURNEY TO EL YUNQUE*

The El Yunque rainforest is one of the top tourist attractions in Puerto Rico, with over one million visitors per year. It is also the only tropical rainforest in the U.S. National Forest System. As a child, I (first author) visited El Yunque on numerous occasions during family visits to my maternal grandmother's house in Puerto Rico. As with many other Puerto Ricans, El Yunque holds a special place in my heart as the location of numerous excursions along the trails and waterfalls of the rainforest with my parents, siblings, and extended family. However, it was in the summer of 1997 that El Yunque took on a new significance for me when I brought my wife and children to Puerto Rico. I had recently completed a doctorate in the learning sciences at Northwestern University and was working for the NASA Classroom of the Future program at Wheeling Jesuit University in Wheeling, WV. While visiting El Yunque, my new lens of the learning sciences provided a vision for sharing a part of my cultural heritage and a national treasure with students throughout the United States.

In the bookstore of the El Yunque visitor center, I came across a book on El Yunque called *Where Dwarfs Reign* by Kathryn Robinson (Robinson, 1997). The book provides a rich historical, cultural, and biological background of El Yunque. The book also featured Fred Scatena, who was a hydrologist for the International Institute for Tropical Forestry—a division of the U.S. Forest Service. I contacted both of them and they agreed to be a part of a potential educational project about the hydrology of El Yunque.

Our first attempt at a grant proposal was turned down in summer 1998. Shortly thereafter, in September 1998, Hurricane Georges, a Category 3 hurricane, struck El Yunque, causing extensive damage to the forest (see Figure 1). This natural disaster created an opportunity to build an educational program around the role of hurricane disturbance in the El Yunque rainforest. I enlisted the help of Steven Croft, a NASA Classroom of the Future colleague. I had been collaborating with Croft, a planetary geologist, for several years on an astronomy program, called *Astronomy Village: Investigating the Solar System*. Croft and I secured a travel grant from NASA Classroom of the Future to visit Puerto Rico, collect images of the damage, and meet with Robinson and Scatena in person to continue planning for a resubmission of a grant proposal.

During our initial face-to-face meeting in Puerto Rico, Scatena suggested that Croft and I also talk with Jess Zimmerman (second author), who was the principal investigator for the Luquillo Long-Term Ecological Research (LUQ LTER) project at the University of Puerto Rico. LUQ LTER had been studying the effects of hurricane disturbance on El Yunque since 1988, just prior to Hurricane Hugo striking El Yunque as a Category 5 hurricane in 1989. LUQ LTER researchers had been tracking the successional regrowth of the forest after Hurricane Hugo and were investigating how the rainforest might be altered if severe hurricanes were to strike the rainforest more frequently as suggested by a variety of climate models.

FIGURE 1. Image of damage from Hurricane Georges taken two months after the hurricane.

Zimmerman agreed to serve as an advisor to the project, but was initially reluctant to get directly involved in the development of the program. This reluctance stemmed from a concern about becoming overcommitted on too many projects, particularly one with which he was unfamiliar. Zimmerman's exposure to middle school classrooms was very limited, so he had a difficult time envisioning what an educational program might look like. Also, there were few rewards for scientists to become involved in education programs. Scientists are judged by their research productivity. Outreach activities are often viewed as a distraction from that primary responsibility.

With confirmation of commitments from Scatena and Zimmerman to serve as advisors and Robinson to serve as a content author, Croft and I discussed the project idea with our *Astronomy Village* program officer at the National Science Foundation (NSF). She concurred that an educational program about El Yunque would provide a valuable extension to the *Astronomy Village* instructional model and that there was urgency to collect data and media resources to document the rainforest recovery after Hurricane Georges. She awarded the NASA Classroom of the Future a one-year Small Grant for Exploratory Research to support the development of an initial prototype around the impact of Hurricane Hugo on the coquí frog population.

The initial project meeting occurred in June 1999—eight months after Hurricane Georges. At that meeting, Croft and I provided Scatena and Zimmerman with a demonstration of *Astronomy Village*. The focus of the demonstration was showing how *Astronomy Village* was an instantiation of an instructional model heavily influenced by the philosophy of John Dewey, as exemplified by the quote below.

> *"As soon as [students are] possessed by the emotional attitude of the group, [their] beliefs and ideas will take a form similar to those of others in the group. [They] will also achieve pretty much the same stock of knowledge, since that knowledge is an ingredient of [their] habitual pursuits"* (Dewey, 1916, p. 14)

This century old quote from John Dewey turns modern education on its head. Dewey believed that the core driver in education should be an emotional connection to communities of practice. Instead, the core driver at that time was, and still is, increasing student achievement (at all costs). Building emotional connections to communities of practice is left to school guidance counselors and informal learning environments. Even then, the financial constraint of increasing achievement often limits an underprivileged school's ability to foster an emotional connection. Field trips to informal learning environments are the first activities to get cut when extra money is needed for tutoring (Ripley, 2004). Programs like *Astronomy Village* can inspire students to find their calling in life by balancing achievement and an emotional connection to the scientific community. *Astronomy Village* places students at the forefront of astronomy by presenting scientific questions that were as yet unresolved, but still approachable to students (e.g., "What does the surface of Pluto look like?"). By embracing the scientific question of the module, students become possessed by the emotional attitude of the group (Shin & McGee, 2003b). *Astronomy Village* then supports student achievement by providing access to scientific data and analysis tools that enable students to make progress in investigating the scientific question.

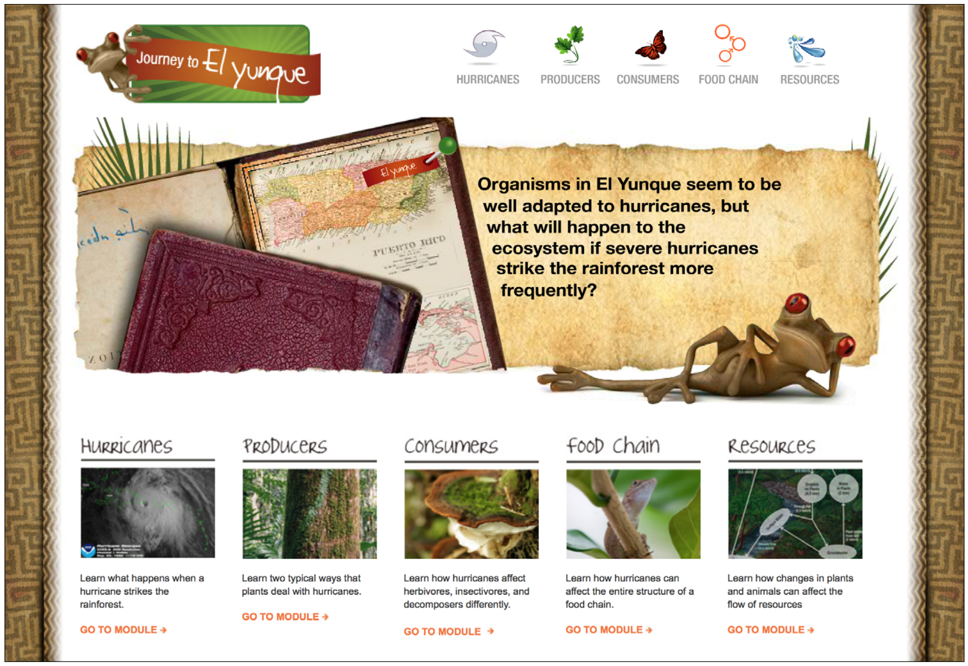

FIGURE 2. Introductory Interface for *Journey to El Yunque*.

The demonstration of *Astronomy Village* opened Scatena's and Zimmerman's eyes to the possibilities of what could be done with the scientific research in El Yunque and provided a concrete model for what the El Yunque educational program might be like. We decided that one of the primary research questions in LUQ LTER could serve as the primary research question for this unit on El Yunque, namely, "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?" Ecologists in El Yunque examine this question by investigating the patterns of response by different species. A hurricane alters access to food, ability to hide from predators, and the environmental conditions species need.

For the prototype, we decided to focus on the coquí frog. Through the end of 1999 and most of 2000, we developed and pilot tested the prototype, which included background readings about the coquí, an interactive model of coquí population dynamics, and a collection of panoramic images of locations in the rainforest. The process of developing the prototype melted away Zimmerman's initial reluctance in becoming directly involved in the development of the program. My demonstrated commitment to LUQ LTER outreach encouraged him further. The close interaction with Croft and me as designers had helped Zimmerman to develop a vision of what is possible with middle school science education. In addition, having a strong outreach program was becoming increasingly important for continued funding of LUQ LTER (Willig & Walker, in press). On the basis of the prototype, we were able secure a development grant from NSF, starting in 2002. Thus, *Journey to El Yunque* was born. The next section will describe the experience of using *Journey to El Yunque*. Subsequent sections will describe the development process that led to the initial publication of the *Journey to El Yunque* program.

EXPERIENCE OF *JOURNEY TO EL YUNQUE*

The *Journey to El Yunque* program is a multi-week middle school ecology curriculum unit that takes students on a virtual journey to the El Yunque rainforest (http://elyunque.net). The materials are published in English and Spanish. Upon entering the website, students are presented with the main investigation question along with the coquí mascot of the website (see Figure 2). The interface provides visual elements suggestive of maritime exploration (e.g., map on faded paper).

Hurricanes Module

Typically, students begin their investigation in the Hurricanes module. There are background readings about hurricanes in general and Hurricane Georges in particular. There is a video news report from the day Hurricane Georges struck Puerto Rico as well as satellite photos showing the path of the storm. This is an optional module that provides students with background on the damage that a hurricane like Georges can cause. During the unit, students will use data collected after Hurricane Hugo for their investigations.

Producers Module

After completing the Hurricanes module, students begin work on the Producers module and investigate what happens to two representative producers in El Yunque after a hurricane. On the first day of the module, students are presented with a diary written by two fictitious children, Alberto and Nicole. They live near the rainforest with their parents, who are both botanists. The children spend a great deal of time in the rainforest and each has become attached to a particular tree species and are constantly squabbling over whose tree is better. Nicole is attached to the tabonuco tree, which is a long-lived, sturdy tree. It is slow growing and usually is predominant if there has not been a hurricane for many years. Therefore, it is considered a mature forest species. Alberto is attached to the yagrumo tree, which is fast growing and thrives in the high light conditions that are prevalent after a hurricane. It is a pioneer species since it is one of the first to recover after a hurricane. In an attempt to put an end to the squabbling, the parents asked Alberto and Nicole to write a diary explaining the reasons they are attached to each tree. In *Journey to El Yunque*, the students have the opportunity to read this diary and enter the debate between Alberto and Nicole. The diary entries address necessary habitat conditions, the niche or role that each species plays, and the hurricane survival strategies.

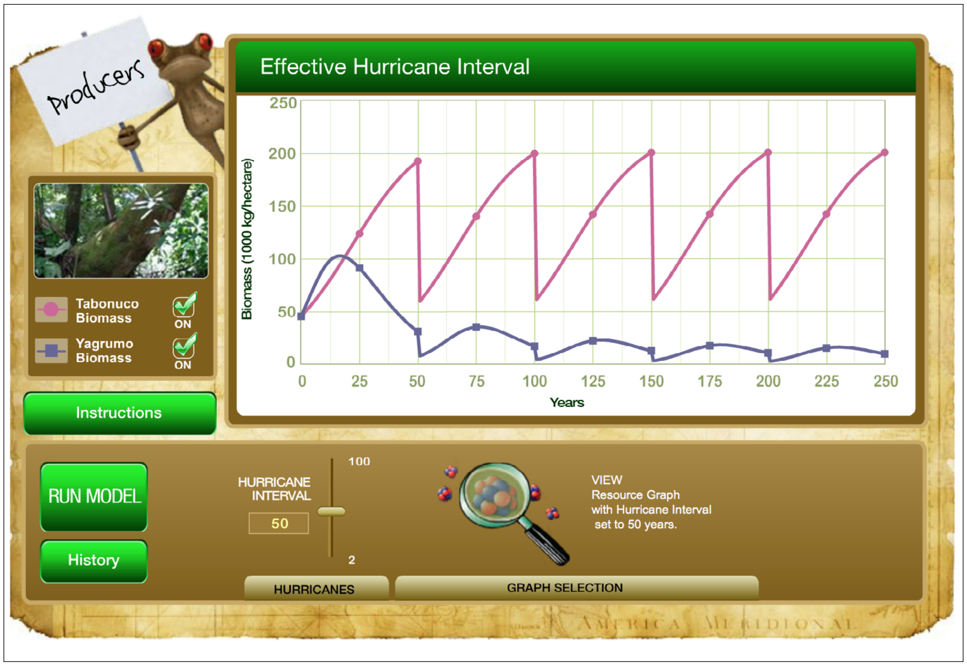

FIGURE 3. Producer model.

The Coqui Chronicle

The number one newspaper for the resident tree frogs of El Yunque

A Frog Metropolis

Stand in the middle of a tropical forest in Central America. You see many kinds of animals. You see colorful birds and butterflies. You see large animals like jaguars and smaller animals like moneys. They form part of the forest community.

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A Coqui Story

The Favorite Recipes of El Verdian Coquies

by Carlitos Coqui

The Reproductive Hall of Fame

MORE THAN JUST A FROG

The Coqui of Puerto Rico

Editor's note: Welcome to another edition of the Coqui Times! For our lead article by Emily Proctor, Ph.D., Dr. Proctor is an educated homo sapien. She wrote this for a local island newspaper. You might find the article interesting, or you might find it dumb. We hope it makes you think.

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Real Estate Agent, Carmen Coqui, talks about the perfect place to live.

Editor's note: This interview took place between Carmen Coqui and your humble servant...

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Editorial: Why just at night?

by Carmen Coqui

All coquis know that lizards and frogs are the two main contenders for the food supply in this forest.

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Hurricanes: Horror or help?

The rabijunco is a local bird that lives along the coast. English speakers call it the magnificent frigate bird.

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FIGURE 4. The Coquí Chronicle.

In the capstone of the Producers module, students explore how hurricane frequency influences the distribution of pioneer and mature forest species. Students are presented with a blank graph and can manipulate the hurricane interval as an input parameter for a model of tree population dynamics. Each time the students change the hurricane interval and press "Run Model", the program draws the model output as a graph (see Figure 3). The model output shows that each time a hurricane hits El Yunque, both trees show a significant drop in biomass due to the destruction of the hurricane. The tabonuco slowly returns to the pre-hurricane levels, just before the next hurricane hits. The yagrumo increases in the first part of the recovery period. However, when the tabonuco forms the canopy and the understory becomes shady, the yagrumo begins to decline since there is less sunlight available. If hurricanes struck the rainforest less frequently, the rainforest would be dominated by mature forest species, such as the tabonuco. If hurricanes struck the rainforest more frequently, the rainforest would be dominated by pioneer species, such as the yagrumo. The historical average hurricane interval in El Yunque has been between 50-60 years (Waide et al., 2013), which the model shows as the interval that allows both species to thrive.

Consumers Module

After exploring the destruction caused by hurricanes and the impact of hurricanes on producers, students investigate what happens to the consumers in El Yunque after a hurricane. Teachers typically assign students to investigate one of the six consumers that are representative of the types of hurricane responses researchers have found in El Yunque. Students might be assigned to mushrooms or snails (decomposers), caterpillars or walkingsticks (primary consumers), or coquí frogs or anole lizards (secondary consumers). The module begins with students conducting background reading on the life history of their assigned consumer, such as the coquí frog. In order to boost interest in the readings, we designed them to convey the scientific information through a fantasy context.

For the coquí frog, the life history is introduced through the Coquí Chronicle, "The number one newspaper for the resident tree frogs in El Yunque" (see Figure 4). To learn what the coquí eats, students can read about Chef Carola's favorite recipes. To learn about coquí predators, students can read the obituary. To learn about important environmental conditions, students can read an interview with Carmen Coquí, who is the number one real estate agent in El Yunque. Finally, there is a hurricane survival guide in the newspaper. Students take notes on the readings using a worksheet table format. There is a row for each of the five limiting factors: food, predator, drought, debris, and hurricane survival. Students enter their notes about the various limiting factors in the corresponding row for each factor.

Over the years, we have had mixed reactions to the use of anthropomorphism in the background readings. The reviewers of the original grant proposal that funded the initial development of *Journey to El Yunque* expressed concern that the fantasy context would send mixed messages about the scientific process and compromise the authenticity of the investigations students were conducting. At a teacher advisory committee meeting in January 2004, the teachers felt that the balance between the fantasy context and content substance had tipped too much towards fantasy context. They felt that students needed access to more scientific facts about the species. On the other hand, we have had many teachers and scientists express their enjoyment of the fantasy context and provide their encouragement of this approach.

While acknowledging these concerns, we made the decision to keep the fantasy context for the background readings. We believed the benefits of the fantasy context outweighed the authenticity costs. We believed that the fantasy context would increase student interest in the reading material and would lead to increased processing and retention of the material. The overall goal of the program is not to teach students how to conduct background research. The focus is on teaching students how to analyze data and draw conclusions. However, in the end, our intuitions about the benefits of the fantasy context and the mixed concerns from scientists and teachers did not come to fruition.

In a recent study comparing the fantasy context to parallel expository versions of the readings, we found that there were only small differences in the level of interest for the narrative versus the expository versions and there were no statistically significant differences in students' ability to extract the relevant scientific ideas about the targeted species in the readings (McGee, Durik, & Zimmerman, 2015). Therefore, in future versions we are likely to include only the expository versions of the readings.

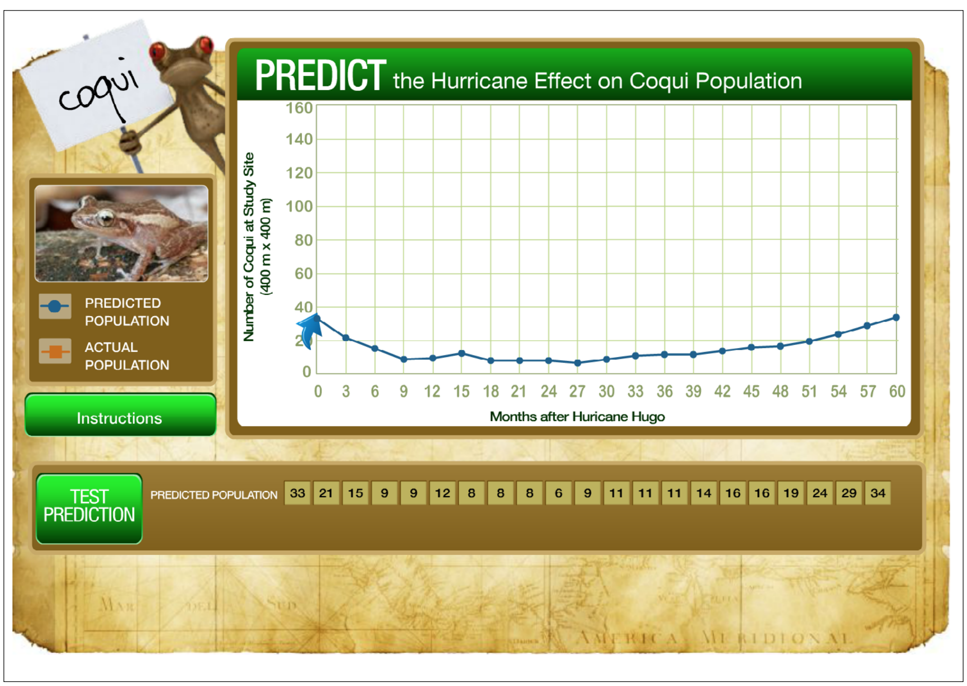

FIGURE 5. Example of a student prediction of coquí population levels after a hurricane.

After completing the background readings and taking notes about the limiting factors that affect the coquí, the next step in the cycle of investigation is to make a prediction about the population levels of coquí over the 60-month period after Hurricane Hugo. The students are presented with a blank graph and asked to draw a line representing what the population levels were each quarter over 60 months. The graph has an arrow indicating what the population level was just prior to the hurricane. Figure 5 shows a typical student drawing. When students are satisfied with the graph they draw, they provide a rationale for their prediction using what they learned in the background readings about the limiting factors. Students click on "Test Prediction", which reveals the actual data that ecologists collected in El Yunque. Students can compare their graph to the graph of actual data and revise their explanation for the pattern of response by the coquí.

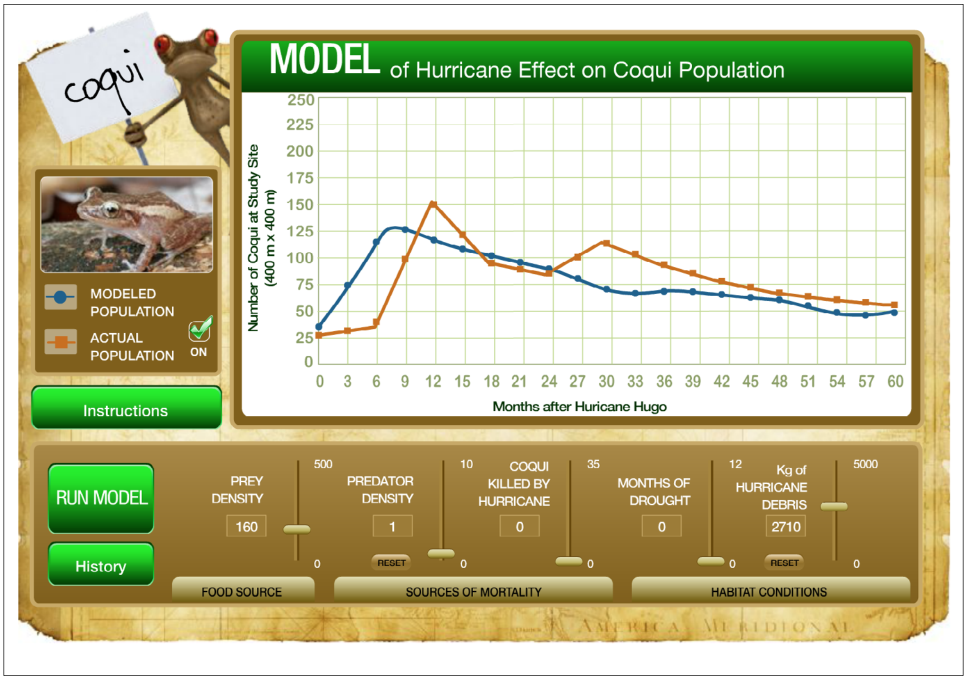

FIGURE 6. Sample output from a model run testing the model parameters against the actual data.

In the final modeling activity for a given species, students are shown a graph of the actual data in orange (see Figure 6). They are able to alter the starting conditions for the five limiting factors: prey density, predator density, number killed by the hurricane, initial months of drought, and kilograms of hurricane debris. The default settings represent the pre-hurricane levels of these limiting factors. After students change the starting conditions, they can run the model again and compare the model output in blue to the actual data in orange.

For the coquí, the increased hurricane debris provides hiding places and protection. In addition, the destruction of the forest canopy increases the amount of light reaching the forest floor, which provides a productive environment for shrubs and flowers. The increased number of shrubs and flowers increases the number of insects that feed on them. The increase in insects provides additional food for the coquí. Thus, the aftermath of the hurricane provides a beneficial environment for the coquí. Increasing these parameters in the model creates a model output that approximates the pattern of response to the hurricane.

During the implementation of the beta test version of *Journey to El Yunque*, we noticed that students were simply using trial and error to find the combination of settings that minimizes the distance between the model output and actual data. Based on their responses to the final explanation of what happened to the targeted species after Hurricane Hugo, we confirmed that students were not applying what they had learned in the readings.

There is a body of research on cognitive overload that supports what we were observing. Having students engage in goal-directed problem solving (e.g., match the model to actual data) before exploring the problem space oftentimes inhibits learning (Sweller, 1994). The cognitive overload research provided a viable explanation for students' inability to apply what they read to draw conclusions from the model. In order to reduce students' inclination to engage in trial and error to meet the goal of the modeling activity, we followed Sweller's (1994) recommendation that we engage students in non-goal-directed exploration prior to engaging in goal-directed problem solving. Therefore, we added a step in the investigation cycle in between the prediction activity and the final modeling activity where students are given the same modeling environment, but without the actual data orange line. They are told to explore the model parameters to understand how each limiting factor affects the population. After the exploration of the model, the students engage in the goal-directed modeling activity. Once students' model output comes sufficiently close to the actual data, the students use the results of the modeling process to generate an explanation of how the altered conditions after the hurricane impact the target species.

Food Chain Module

After all of the students have completed investigating their assigned consumer, the class comes together for a discussion about the relationships among the six consumers. In particular, the students examine one food chain relationship among four of the species they have studied: tabonuco tree, yagrumo tree, caterpillar, and anole lizard. The caterpillar eats the yagrumo leaf and the anole eats the caterpillar. The yagrumo competes with the tabonuco for space and light.

Students start by running the model with the caterpillar and anole excluded to see what the impact would be on the yagrumo and tabonuco if there were no caterpillars feeding on the leaves of the yagrumo (see the top screenshot in Figure 7). Next, students run the model a second time with the caterpillar included and the anole lizard excluded (see the bottom screenshot in Figure 7). Caterpillars eat the leaves of the yagrumo, which suppresses their population numbers and benefits the tabonuco tree. Lastly, the students run the model again including the anole lizard, which eats the caterpillar and suppresses their population levels. With fewer caterpillars, the yagrumo increase in number and the tabonuco decrease slightly. The activity provides a demonstration of the connectedness of the feeding relationships in an ecosystem.

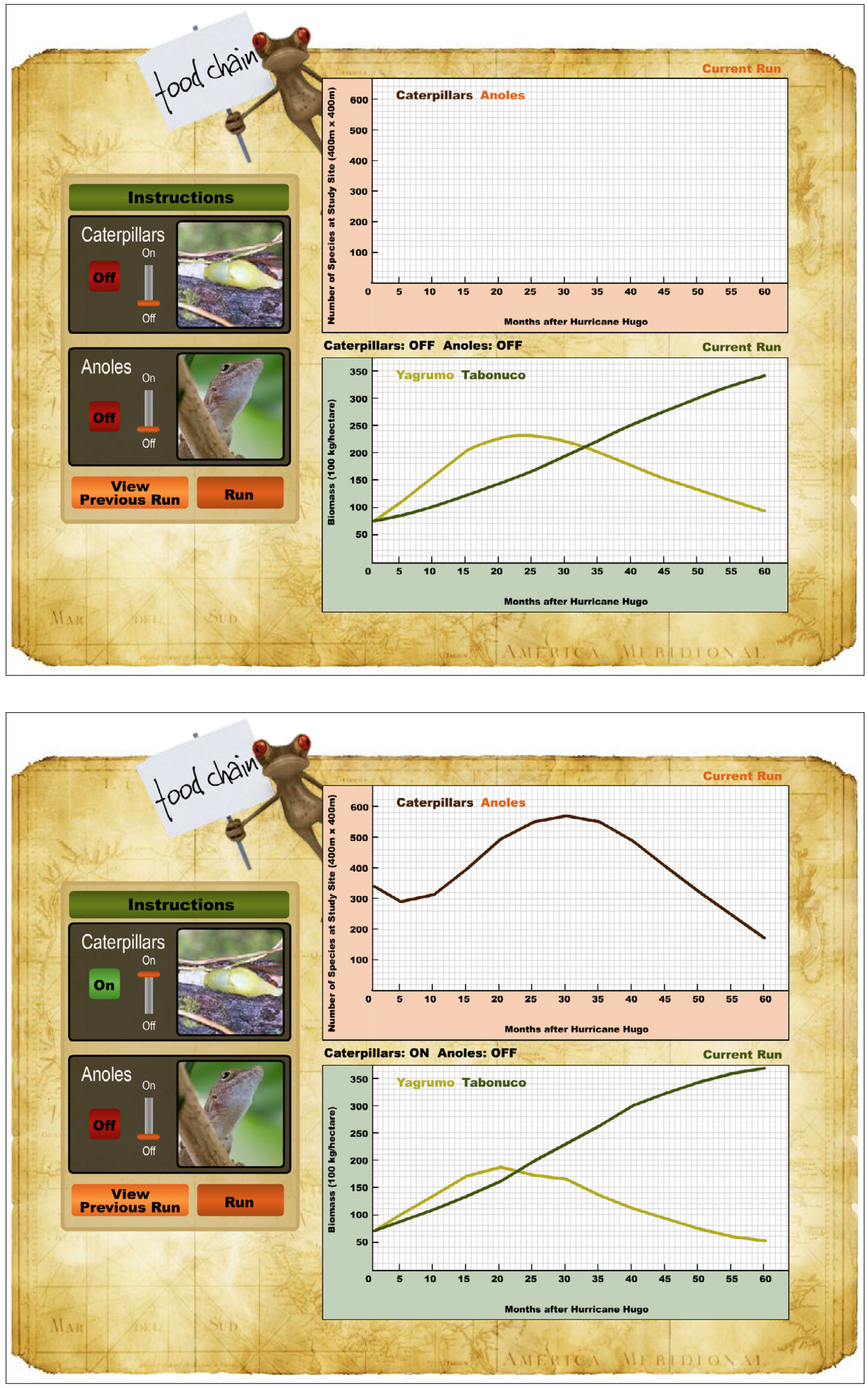

FIGURE 7. Food chain models excluding and including the caterpillar.

Resources Module

In the last module, students investigate what happens to the abiotic resources after a hurricane. Students can examine illustrations of the rainforest 3 months before a hurricane, 3 days after a hurricane, and 3 years after a hurricane (see Figure 8). Students can overlay the water cycle, carbon cycle, and nitrogen cycle over each illustration to see how the flow of resources changes. Students then use their knowledge of the life history of various species in the rainforest and the population dynamics of these species after a hurricane to explain changes in the resource cycles. For example, a significant driver of cloud formation over the rainforest is the transpiration that occurs in the trees. However, if the trees have been destroyed during the hurricane, the level of transpiration significantly reduces, which reduces the amount of rainfall after a hurricane. As the producers in El Yunque recover, the level of transpiration increases.

INSTRUCTIONAL DESIGN MODEL

At the time we started development of *Journey to El Yunque*, the two most prominent instructional design models in the science education literature were the BSCS 5E instructional model (Bybee et al., 2006) and the cognitive apprenticeship framework (Collins, Brown, & Newman, 1989). While there

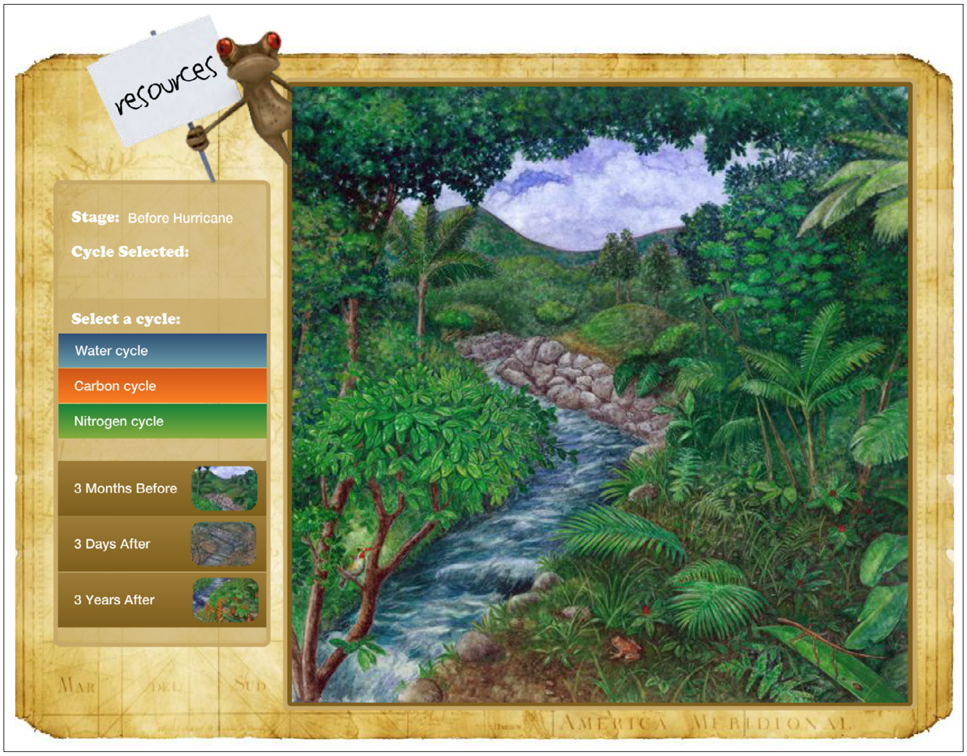

FIGURE 8. Screenshot of the 3 days after illustration from the resources module.

are many benefits to the 5E model, we developed *Journey to El Yunque* using the cognitive apprenticeship framework. The 5E model emerged in the late 1980s as an extension to the Sputnik-era learning cycle (Lawson, 1989). Within 5E, designers organize learning activities to support conceptual development. The 5E model emphasizes motivating an investigation by presenting puzzling phenomena and providing opportunities to explore, followed by explanation and synthesis for transfer. Numerous studies have demonstrated the benefits of 5E on student learning (Bybee et al., 2006). However, in our view, the 5E model is biased towards acquisition of science knowledge without explicit attention to the practices of science (Sfard, 1998).

In contrast, we felt that the cognitive apprenticeship framework better matched our goal of connecting students with the LTER community of practice. The cognitive apprenticeship instructional framework was developed as an outgrowth of theories of situated cognition that had emerged in the 1980s (Brown, Collins, & Duguid, 1989; Sfard, 1998). Cognitive apprenticeship extends traditional notions of apprenticeship to articulate ways that school subjects can be oriented so as to engage students in authentic inquiry that builds an emotional connection to a community of practice and helps students develop a deeper understanding of the core disciplinary ideas. Cognitive apprenticeship identifies three key features of instructional practice that facilitate this connection: (a) student inquiry in classroom settings should reflect the goals of a scientific community of practice, (b) the cognitive expertise of community members must be made explicit so that students can see the cognitive steps that are implicit and teachers can monitor student progress in adopting those practices, and (c) the order in which the steps of inquiry are learned is often the opposite of the order in which those steps are followed in practice. Below is a description of how we consistently implemented these three principles within *Journey to El Yunque*.

Student Inquiry Reflects the Goals of the El Yunque Research Community

Journey to El Yunque engages students in the same problems that researchers in El Yunque are investigating. Cognitive apprenticeship suggests that connecting students with the community of researchers in El Yunque starts by connecting students to the goals of the community. We have found that the El Yunque research program is quite compelling for students, which is why we are able to present students with one of the overarching scientific questions El Yunque researchers are investigating: "Organisms in El Yunque seem to be well adapted to hurricanes, but what would happen to the ecosystem if severe hurricanes struck the rainforest more frequently?" It makes an ideal question for middle school students to investigate because it is an unknown for scientists, it piques students' curiosity, and it is readily understandable (Shin & McGee, 2003a, 2003b).

Cognitive Expertise is Made Explicit

One important technique El Yunque researchers use to examine the impact of hurricane disturbance on the ecosystem is investigating the population dynamics of various species. Investigating population dynamics involves examining and explaining the changing abundance of specific species. Researchers in El Yunque have found four characteristics that explain the majority of the variance in population dynamics after a hurricane. These characteristics are access to food, avoidance of predators, direct mortality from the hurricane, and suitability to changes in environmental conditions. Hurricanes bring an abundance of debris and sunny conditions from the destruction of the forest canopy. These altered conditions can affect a species directly as well as indirectly by affecting their food and predators. We made this ecological cognitive expertise explicit for students in the activity instructions, background readings, and model interfaces.

Student Learning is Focused on the Last Steps of the Inquiry Process

Students new to the inquiry process have difficulty engaging in the complete process of scientific inquiry. Cognitive apprenticeship suggests that students should learn the process step by step. In most cases, cognitive apprenticeship suggests that students learn the steps of inquiry in the opposite order in which they would conduct inquiry. For *Journey to El Yunque*, this recommendation suggests that student learning should focus on the last steps of the inquiry process—data interpretation and drawing conclusions from data. As suggested by the cognitive apprenticeship model, students are guided through the early steps of the inquiry process—research question, investigation design, data collection, and data analysis. Students are given a question to investigate based on the goals of research in El Yunque. The investigation design and data modeling are provided to students. During the unit, students are expected to interpret the data on population dynamics and use that interpretation to draw conclusions about the investigation question.

DESIGN PROCESS

Within the context of the cognitive apprenticeship framework, we set out to mimic the culture of LTER research in El Yunque. We sought to foster students' connections to the goals of the community and to support students in using practices consistent with the El Yunque research community. A primary El Yunque research goal is to understand how the relationships among the components of the El Yunque ecosystem change across space and time, particularly in response to disturbances such as hurricanes and droughts. Culturally, ecologists in El Yunque tend to specialize in studying how one type of species or component of the ecosystem changes over time. These individual ecologists gather as a whole El Yunque community at least annually. At that meeting, the individual ecologists present the results of their research and the community as a whole discusses how the research on individual species informs their understanding of how relationships within the system change over space and time. In other words, understanding of the ecosystem as a whole is developed through investigating individual components.

In order to support students in building an understanding of the ecosystem as a whole, we mimicked the culture of studying how the components of the rainforest change over time and then identifying the relationships between the components. Graphs of population size over time are used to represent the temporal changes that occur to a specific species. Students and ecologists investigate the factors that affect how the populations change over time. To move from investigating species to investigating the relationships between components of the system requires representations other than graphs. For example, spatial relationships among species are often represented as a food web, which shows the feeding relationships between organisms that share the same space. Cycle diagrams provide a representation of how matter and energy flow through an ecosystem. While expert ecologists can move seamlessly between the temporal representations (e.g., graphs) and spatial representations (e.g., food web, cycle diagram), students need help in synthesizing temporal and spatial information across the different types of representations.

Throughout the design process, we attempted to create coherence between the relationships and components of the El Yunque ecosystem. Our design rationale focused on students being able to examine both the temporal dynamics of individual species as well as examine their relationships within the food web so that students would more likely build a coherent, systemic understanding of the ecosystem. In the sections that follow, we will provide an overview of the development timeline and then discuss how the cognitive apprenticeship framework informed (a) our selection of investigation goals, (b) how we made ecology expertise explicit across activities, (c) how our representations of data for interpretation evolved and (d) how we enabled student achievement by embedding the science standards within the El Yunque community of practice.

Development Timeline

Table 1 shows the development timeline for *Journey to El Yunque*. As discussed above, we were awarded an exploratory grant in 1999 to develop a prototype of the coquí module. NSF awarded our first development grant in 2002. We were able to evaluate the alpha version developed with the exploratory grant. We also proceeded through two additional rounds of development and testing. We published the first edition of the website in 2006. Near the end of the

1999—2002	Development of alpha version.
2002—2003	Pilot test alpha version and develop beta version.
2003—2005	Pilot test beta version and develop summative version (Croft left the NASA Classroom of the Future and the *Journey to El Yunque* project).
2005—2006	Summative evaluation. (I left NASA Classroom of the Future and moved the project to The Learning Partnership).
2009—2010	Interface redesign.

TABLE 1. Development timeline.

development of the first edition, Croft and I left the NASA Classroom of the Future. Croft went to work for an astronomy outreach organization and no longer worked on *Journey to El Yunque*. I moved to The Learning Partnership and brought the *Journey to El Yunque* project with me.

In 2009, we received funding from the LTER program to redesign the interface and complete the resource cycling module. We published the redesigned version in 2010. Throughout the 10-year development process, we have kept the cognitive apprenticeship framework at the forefront of our thinking about the design of the program.

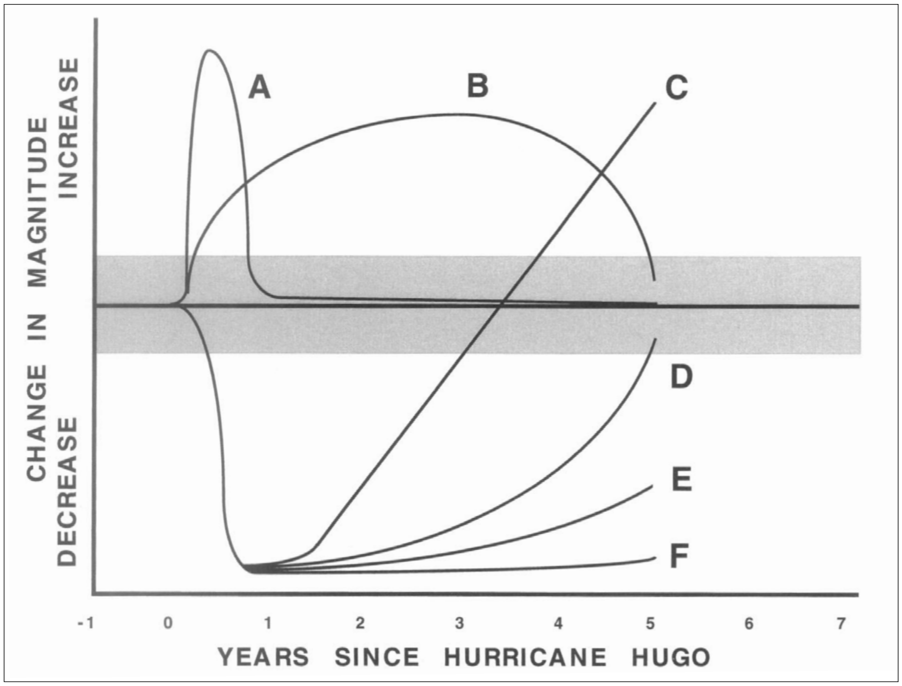

FIGURE 9. Idealized 5-year trajectories of responses of different components of El Yunque to Hurricane Hugo. Reprinted from "Introduction: Disturbance and Caribbean Ecosystems," by J. K. Zimmerman, M. R. Willig, L. R. Walker, and W. L. Silver, 1996, *Biotropica, 28*(4), p. 417. Copyright 1996 by the Association for Tropical Biology and Conservation.

Finding the Overlap between Scientific and Pedagogical Goals

According to the cognitive apprenticeship framework, student inquiry should reflect the goals of the El Yunque research community. Therefore, we sought to identify a collection of species in El Yunque that would both allow teams of students to productively investigate how population levels of individual species change over time and be able to spatially connect those species through a food web.

In addition to its authenticity to the culture of research in El Yunque, focusing on a specific component of a system and then working with students to build understanding of the system as a whole is also a recognized cooperative learning approach called the jigsaw method (Aronson & Patnoe, 2011). In this method, students become experts on a particular component of a system (i.e., individual species), and then work with peer experts who studied other components of the system to build understanding of the system as a whole (e.g., food web). A benefit of this approach is that every member brings unique expertise to the discussion. The resulting interdependence among the group members is an important feature of successful cooperative group functioning (Cohen, 1994).

We also considered other criteria for the target species. We wanted to select organisms that have charisma so that at a surface level students would have initial interest in learning more about them. On a pragmatic level, we needed to select species that were well researched and had data available about their response to a hurricane. Unfortunately, we realized early in the design process that it would not be possible to meet these criteria and end up with a collection of species that would be connected through food web relationships.

The pedagogical need to connect the temporal dynamics of individual species into a food web was not well supported by the research priorities of the El Yunque researchers. The issue was not a lack of information about the food web since the researchers in El Yunque have produced one of the most comprehensive food web studies in the field of ecology (Reagan & Waide, 1996). The issue is that a species' response to the hurricane is not related to its place within the food web. Figure 9 shows six characteristic responses to hurricanes. These typical responses do not correspond to specific trophic levels. For example, some insectivores spiked after the hurricane (Response A - caterpillars), whereas other insectivores significantly declined (Response F - walkingsticks). Therefore the research priority of studying the range of responses to the hurricane deprioritized the connectedness of the species that were the target of research. Therefore, we dropped the criterion that the collection of species forms a food web. Instead, we ensured that the target species were distributed across different trophic levels of the food web: decomposers, primary consumers (herbivores), and secondary consumers (insectivores).

Table 2 shows the species we considered at the initial project planning meetings. In August 2002, Croft, Zimmerman, and I met for a kickoff planning meeting. In November 2002, we met with Gary Belovsky, an expert on ecological modeling,

TROPHIC LEVEL	AUGUST 2002	NOVEMBER 2002	JANUARY 2003
Decomposers	Mushrooms	Mushrooms Snails	Mushrooms (B) Snails (C)
Primary Consumers (Herbivores)	Snails Walkingsticks Hummingbirds	Walkingsticks Caterpillars	Walkingsticks (F) Caterpillars (A)
Secondary Consumers (Insectivores)	Tody bird Coquí frog	Coquí frog Anole lizards	Coquí frog (B) Anole lizards (D)
Tertiary Consumers		Screech owl Puerto Rican lizard cuckoo	

TABLE 2. Candidate lists of species that emerged from early project planning meetings.

to map out how the models would be developed. In January 2003, the teacher advisory board met with us to review the initial plans and provide feedback. At our meeting in August 2002, we picked the best examples of organisms with sufficient data and charisma at each of the trophic levels of the food web. The students would be encouraged to generalize their findings from the species itself to its role in the ecosystem. However, we did not feel at that time that the jigsaw approach would be viable since there was no direct connection among the species at different trophic levels that would support a coherent discussion among the various peer experts.

By the time of the modeling meeting several months later in November 2002, the target list of species had evolved and so had our thinking about supporting the investigation of relationships between species. Through the process of planning out the models of the population dynamics of each species, we began to see opportunities where we could connect the models of different species. For species with a predator-prey relationship, the model output from one species becomes the model input for another species. At that point, rather than find a collection that formed a food web, we identified a subset of organisms that could form a food chain. We swapped the anole lizard (*Anolis gundlachi*) for the tody at the insectivore trophic level. At the herbivore level, we swapped the caterpillar (*Historis odius*) for the hummingbird. The anole lizard eats the caterpillar. The caterpillar eats the yargumo pioneer species of trees that grows quickly in the aftermath of a hurricane. We added a tertiary level of consumers to extend the food chain to another level even though there would not be modules on the tertiary consumers. We also moved the snails to the decomposer level. Since they are an omnivore they could reasonably be placed at the decomposer level or primary consumer level. We selected these species based on the availability of data, the niche within the rainforest, and our impression of the charisma of the species for middle-school students.

By the time of the teacher advisory meeting, we had settled on the final list of species that would ultimately be included in the published version. The last column of Table 2 shows the final list of species by trophic level. The letter in parentheses indicates which typical response pattern from Figure 9 was exhibited by that species. We were able to select species that represented five of the six characteristic responses. Within each trophic level, we were able to identify species with contrasting response patterns. One species at each trophic level spiked after the hurricane and the other declined.

The final food chain had three trophic levels: Yagrumo tree → caterpillar → anole lizard. A food chain with these three species provides a robust example of the key concept of tropic cascade; therefore, we did not need to include a species from the tertiary consumer level for the food chain. A change in the anole population cascades through the food chain to impact the Yagrumo population. With the identification of a food chain using a subset of the target species, we were able to reconsider the inclusion of the jigsaw approach. The students could develop expertise for a particular species in the food chain. In the culminating activity, the students could meet with the experts on the other species in the food chain to analyze how the species in the food chain respond to the temporal dynamics of the other species in the food chain. With the finalization of the list of target organisms, the next section will discuss how we kept the representations of cognitive expertise coherent across activities.

Keeping Representations of Cognitive Expertise Coherent Across Activities

According to the cognitive development framework, it is essential to make the cognitive expertise of the community explicit for students. For ecologists in El Yunque, there are generally five limiting factors that explain most of the variability in population changes after a disturbance, like a hurricane. These limiting factors are (a) access to food, (b) avoidance of predators, (c) survival during the disturbance, (d) access to water, and (e) access to a home. In this section, we discuss how we made these five limiting factors explicit for students in the background readings and modeling activities as well as how we ensured that the readings and models were coherent in representing the limiting factors.

Background Readings

We do not expect students to conduct a literature review as part of the unit. Instead, we provide all of the information that the students need to conduct the investigation. Based on our experience with similar inquiry-based environments, we thought it was important to make the readings as engaging as possible, while making explicit the cognitive expertise of El Yunque ecologists and conveying the background information needed to conduct the investigation. To that end, we hired Kathryn Robinson to develop the background reading materials. She has written on El Yunque for a popular audience. Her book, *Where Dwarfs Reign*, is highly regarded among the scientists in the Luquillo LTER (Robinson, 1997). It accurately conveys the science of El Yunque to a general audience.

At the January 2003 advisory committee meeting for the beta version, Zimmerman and Robinson worked out the content framework for each of the producer and consumer sections. They developed a chart for each species. The rows represented the limiting factors for each species—access to food, predator avoidance, hurricane survival, water requirements, and debris requirements. These concepts represent the cognitive expertise that ecologists use to explain variations in response to hurricane disturbance.

In each row, there was one cell that discussed how that concept was handled by the models that Zimmerman would be developing. The other cell described what target concepts needed to be discussed in the background readings so that the readings aligned with the models. Zimmerman provided Robinson with scientific journal articles to support the content outline. As she did for her book, Robinson used the scientific articles as a basis for the content in the articles. Zimmerman was available for consultation whenever she needed help. He had access to the other scientists in the Luquillo LTER so that he could get specialized knowledge about particular species.

I then reviewed each article to ensure that the elements from the content outline were included in the article and then Zimmerman reviewed the articles for scientific accuracy. As a final step, we analyzed the articles using Microsoft Word's Flesch-Kincaid Grade Level readability index. Robinson rewrote any text passages that were higher than 5^{th} grade and I reviewed them again to keep the overall reading level at 5.9 or below. Robinson's main approach to reducing the reading levels was simplifying the linguistic complexity of the sentences (e.g., multiple short sentences instead of one complex sentence). In no instance did Robinson have to change the scientific explanations or terminology. Once we finalized the readings, we developed a Flash interface to present the readings to the students. We also added photos of each species. We licensed many of the photos from Jerry Bauer, a renowned El Yunque photographer who provided images from *Where Dwarfs Reign*.

Modeling

We support the students in applying what they learned in the background readings to their explanation of the results of the modeling process. Since we co-developed the background readings and the models from the same content outline, the cognitive expertise represented in the background readings aligns to specific parameters in the model. Students organize their notes on the background readings according to the five limiting factors. Therefore, if the students notice that a specific limiting factor has a strong influence on the population dynamics, then the students can use their notes about that parameter to generate an explanation.

Zimmerman developed the models in *Journey to El Yunque* using the Stella modeling software. He started each model by identifying a basic ecological model in Hannon and Ruth (1999) that had similar characteristics to the targeted species. He then synthesized the relevant LTER literature about the target species to develop estimates of the parameters related to the limiting factors. For example, coquí eat about 3 insects per night (Stewart & Woolbright, 1996). Therefore the number of insects that are available will affect the ability of coquí to survive and give birth to new coquí.

Figure 10 shows a map of the coquí systems model that Zimmerman developed in Stella. The map includes all of the parameters that students can manipulate as well as the underlying variables that influence population levels. For example, in the upper left of the map is the prey density factor. Students can set the initial starting condition of prey density. The prey density influences the coquí lambda value, which is the general variable name for the growth rate of a population. The lambda value governs the number of births at each time step in the model. When the model is run, Stella computes all of the values based on the starting conditions and then updates the number of adult coquí at that time step. Stella increments the model to the next time step. It then recomputes all values based on the updated conditions and then updates the number of adults at that time step. The model continues computing the estimate of the number of adults at each time step until the model reaches the maximum time step, in this case 60 months. Once Zimmerman finalized a model in Stella, we copied the model formulas from Stella and pasted them into Flash to create the interface that is seen in Figure 6.

The box in the systems map in Figure 10 highlights an area of the model that is blown up in the right hand panels of the figure. We focus in on these aspects of the coquí model to highlight the connection between the background readings and the underlying model. In the interview with Carmen Coquí the real estate agent, students read that debris is formed from the dead plant matter that litters the forest floor. It provides a moist home, consistent temperatures, a place to hide from predators and a place to lay eggs.

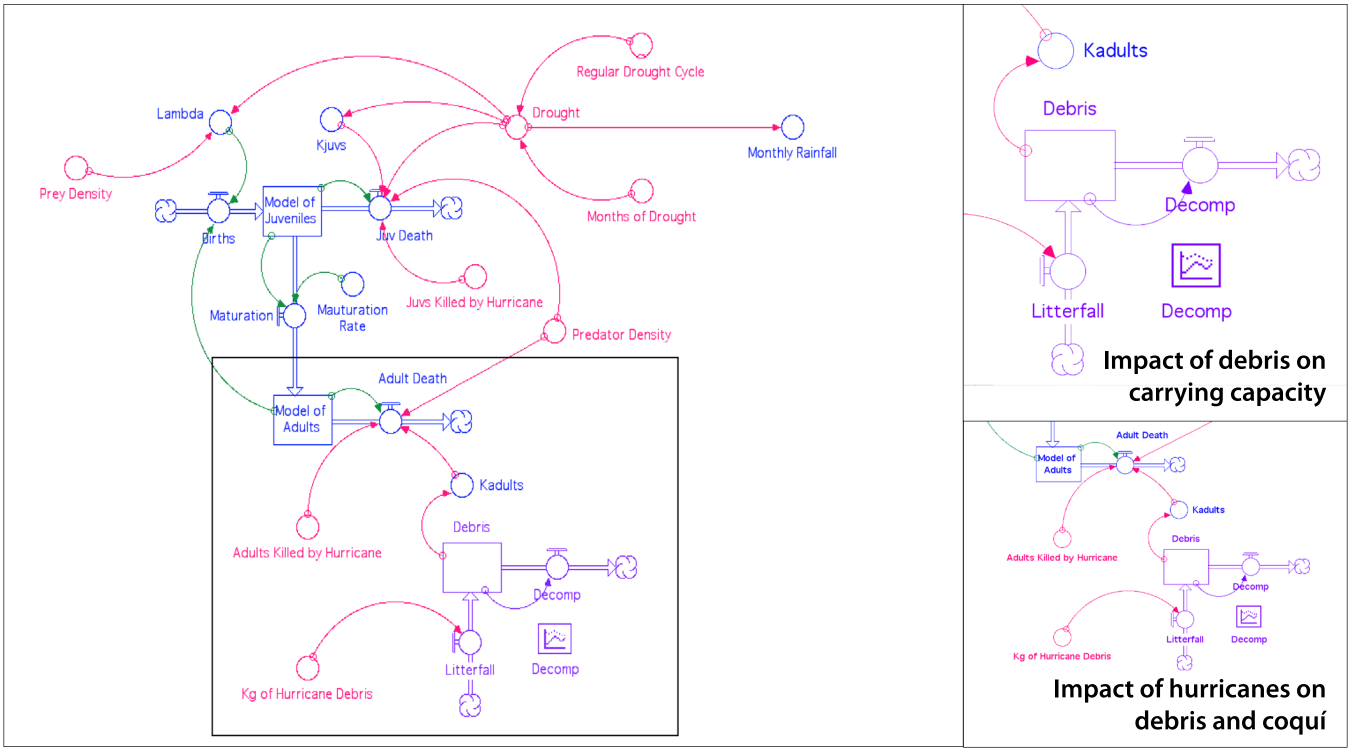

FIGURE 10. Stella model of coquí population dynamics.

> *"Ground matter is extremely important to us in so many ways. It's a place where we can relax in relative safety and hide from our enemies. You heard about Cocoa, didn't you? He hated staying in ground matter. It made him claustrophobic. Well, he met his maker last week."*—Interview with Carmen Coquí in Coquí Chronicle.

The close up of the model in the upper right panel in Figure 10 shows that debris forms from the natural litterfall of leaves as they routinely fall from the trees. Debris disappears at the rate of decay for debris. Debris affects the adult k value, which is the shorthand for carrying capacity. The ecosystem cannot sustain any more coquí than there are places for the coquí to live in the debris. The more debris there is the more coquí there are. The model does not make a connection between reproduction and debris, but it does provide a computational representation of the key benefits of debris as a home as described in the background reading.

In the Hurricane Survival Guide, students read about the dangers that hurricanes pose to the coquí, but also the benefits of the aftermath given the increased amount of debris on the ground.

> *"What can we expect? A hurricane is a noisy, scary event. Of course, many frogs die during such a storm. However, if you take precautions, you should be able to survive. The weeks and months following a hurricane can actually bring benefits to some coquí. The additional debris on the forest floor can result in a marked increase in the coquí population."*—Hurricane Survival Guide in Coquí Chronicle.

The lower right panel in Figure 10 shows two hurricane-related parameters that students can control. Students can specify the number of coquí that are killed by the hurricane. That parameter feeds directly into the number of adult deaths at the outset of the model. Students can also control the amount of debris that is generated by the hurricane, which creates an initial pulse of debris into the system. That initial pulse increases the carrying capacity of the ecosystem and this allows the coquí population to grow over time since they have more places to live.

These two examples provide a sampling of the ways in which we aligned the readings and the modeling activities. Throughout the development process, we compared both the readings and the Stella model components to the content chart. We made adjustments to either the readings or the models to bring them into alignment with the content chart. Ensuring the alignment between the readings and the model parameters creates coherence that makes explicit the connection of the cognitive expertise to each of the activities.

The Evolution of Data Representations for Interpretation

The cognitive apprenticeship framework suggests that students should be supported to engage in the entire process of inquiry while learning the parts of the process step by step. For *Journey to El Yunque*, we focused student learning of the process on the last steps—data interpretation and

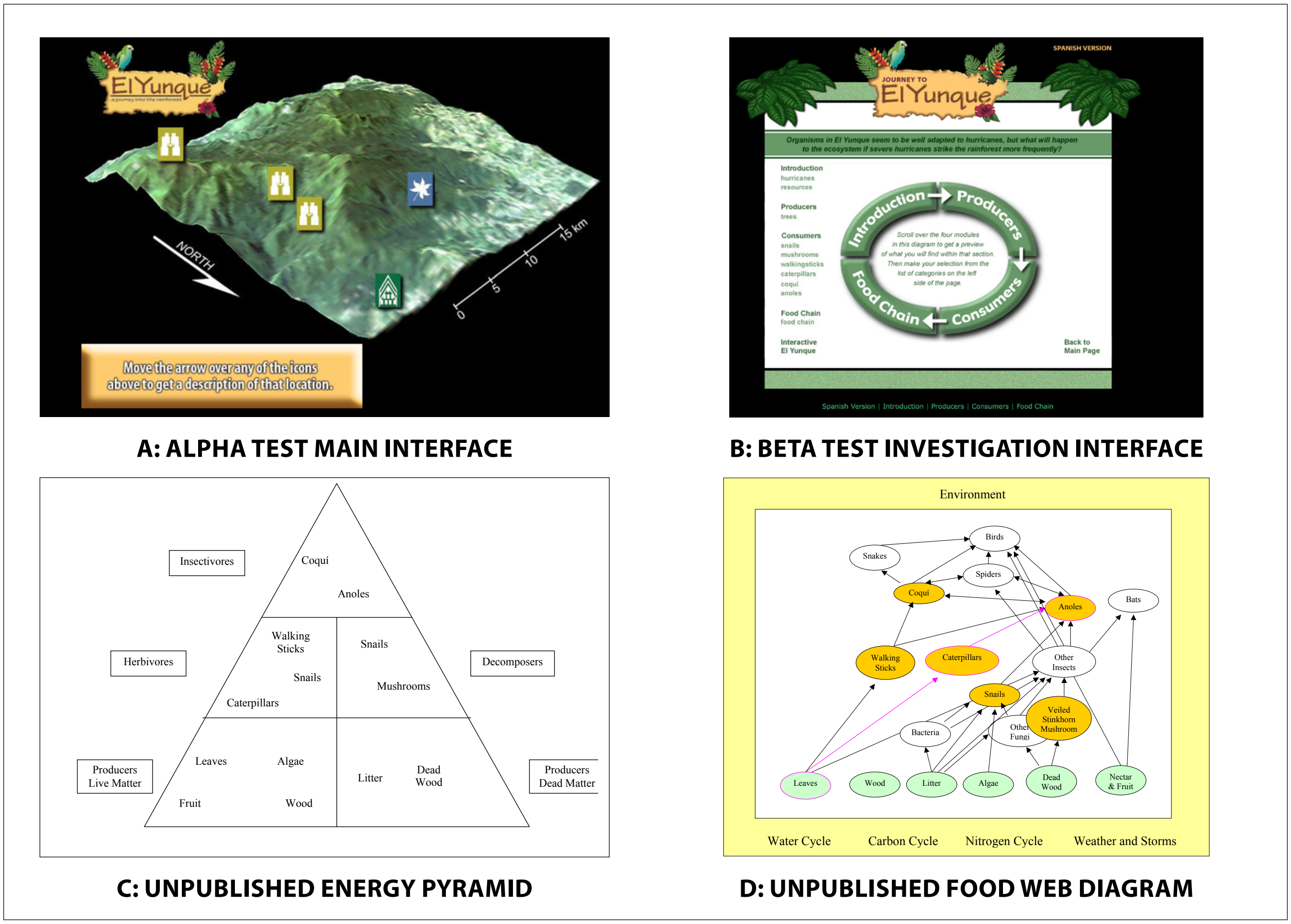

FIGURE 11. Draft interfaces for *Journey to El Yunque*.

drawing conclusions from data. As suggested by the cognitive apprenticeship model, students are guided through the early steps of the inquiry process—research question, investigation design, data collection, and data analysis. Students are expected to interpret data on how populations change over time and connect that data to other components of the ecosystem.

Recall that ecological representations of change over time are different than representations of spatial relationships. It is extremely complex for students to synthesize the different types of representations to draw conclusions. In this section, we highlight three examples of the ways that we have combined temporal and spatial representations of components of the El Yunque ecosystem. In the first example, we discuss the evolution of the interface for navigating to the various activities in the program. In the second example, we discuss the way in which we represent the relationships in the food chain while at the same time showing the temporal dynamics of the population of each component of the food chain. In the third example, we discuss another approach to representing a spatial representation of resource cycling and the temporal dynamics of how the resource cycle changes over time.

Navigational Interface

One of our basic assumptions about *Journey to El Yunque* is that the students who are using the program outside of Puerto Rico are unlikely to have ever visited the rainforest. In our initial attempts at designing the interface for the program, we sought to immerse the students in the rainforest environment as the backdrop for beginning the investigations. The initial interface was heavily influenced by the interface for *Astronomy Village*, which provided students with a mountaintop village interface through which they accessed all of the resources.

Figure 11, panel A, shows a topographic map of the El Yunque rainforest. The three yellow binocular icons represented three locations along the public trails where students could click on the icons to view 360° panoramas of the trail. The blue flower icon represented the location of the main study plot from which all of the data in El Yunque have been collected. We had envisioned that students would click on the blue icon to access the data about the various species, similar to the way that students clicked on a telescope in *Astronomy Village* to access data about the solar system. The green hut icon represented the location of the El Verde field station. Students would click on the hut icon to access the various activity modules, similar to the way that students clicked on the library and the research lab in *Astronomy Village* to access resources about the investigation.

When we presented the proposed alpha test interface at the first teacher advisory committee, there was general consensus that the topographic map used as the interface to the activities was too complex. The map is oriented so that north is pointed towards the lower right corner of the computer monitor. The purpose of orienting the map in that direction is that it provides the best view of the rainforest in 3D. The teachers believed that students would be confused by seeing north pointed in a different direction than towards the top of the screen. We also decided that it would be beneficial to provide students with a set of maps to put El Yunque and Puerto Rico in the context of the Caribbean. It is important to bear in mind that Google Earth had only been released a couple of years earlier in 2001 and that Google Maps would not be released until 2005. The general public was not used to using Geographic Information Systems to access information. With the proliferation of Google Maps and Google Earth on mobile Internet devices, the alpha test interface may have been more familiar to today's middle school students.

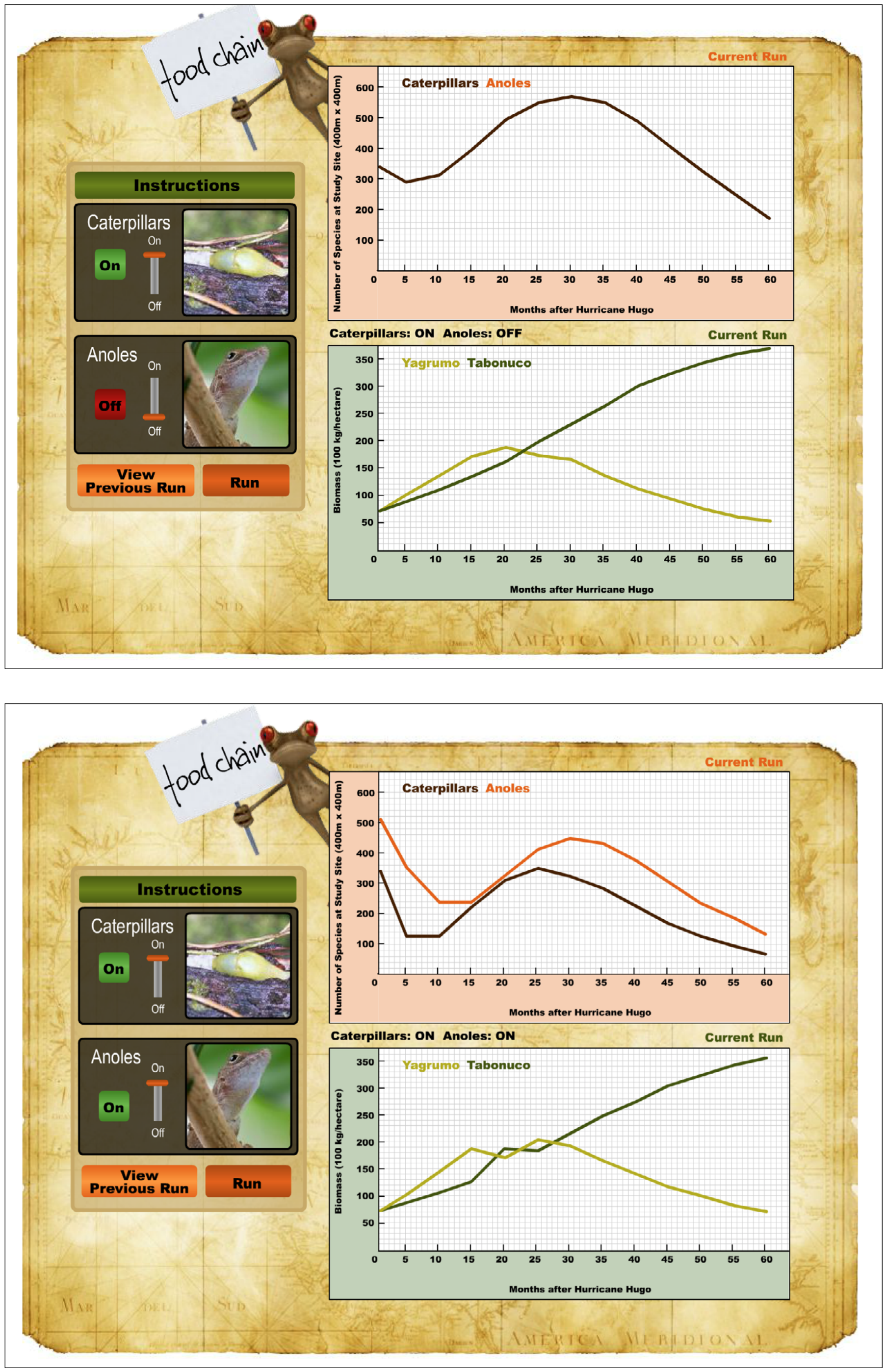

FIGURE 12. The food chain module with and without anoles.

For the beta test and summative version, we simplified the interface to provide the overarching research question and a representation of the pedagogical sequence (see Figure 11, panel B). The spatial dimension had been deemphasized. We kept the alpha version interface and provided a link from the main page to Interactive El Yunque. It served as an interface to the images of the rainforest. It is interesting to note that we originally envisioned the Resources module to be part of the introduction to the program as a way to establish the environmental context for the organisms' survival. We had two concerns about the summative interface. The first is that it was very plain and was inconsistent with the playful nature of the background readings. The second is that it implied a specific sequence to the modules, which represents how we envisioned teachers using the website. However, we also wanted the interface to invite teachers to use the modules in different ways.

Figure 11, panels C and D, are unpublished drafts of interfaces we considered for the final version. We were exploring ways that students would access the modules through an

FIGURE 13. Illustration of hypothetical location in El Yunque 3 days before, 3 days after, and 3 years after a hurricane. Copyright 2006 by Robert Casilla. Used with Permission.

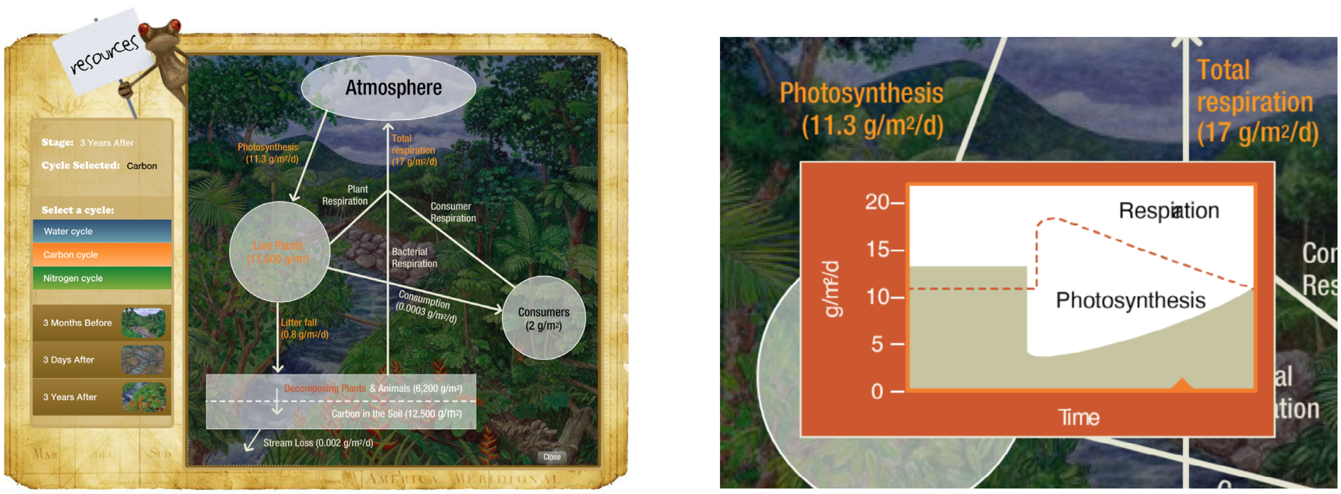

FIGURE 14. Carbon cycling 3 years after a hurricane.

interface that spatially conveyed the important relationships among the targeted organisms. Figure 11, panel C, shows the targeted species in the context of an energy pyramid, which highlights the niche that each species plays in the rainforest. Figure 11, panel D, shows the targeted species (highlighted in yellow) in the context of a food web, which highlights the feeding relationships among a variety of other species (white ovals) in the rainforest. These interfaces might have provided a nice index to information, but they did not convey any sense of what students would be doing in the activities.

In the currently published version of the interface that was developed as part of the later redesign, we combined elements of the alpha and beta version interfaces (see Figure 2). We added a spatial element in presenting a map that indicates where El Yunque is within Puerto Rico. We made the research question more prominent on the front page. We maintained a representation of the suggested pedagogical sequence, but positioned the modules like menus so that teachers would feel it was acceptable to use the modules in a different order. We placed all these elements in a whimsical context. The leather bound diary gives a sense of an explorer. There is also a coquí mascot that appears on every page. Our hope was that the interface would be both appealing to students and give them a sense of where the investigation would be headed.

Food Chain

The Food Chain module follows the students' investigations of the producers and consumers in El Yunque. The activity serves as a way to examine the impact of species at different trophic levels. A key systemic concept in the food chain activity is trophic cascade. Changes at one level of a food chain can affect species at higher or lower levels of the food chain. For example, the removal of higher-level predators could have a negative impact on the producers. Figure 12 shows our attempt to convey both the relationships among species and the temporal dynamics. The relationship is demonstrated through the placement and coloring of the graphs. The green producer graphs are shown below the orange consumer graphs, which is traditionally how food webs are represented with producers at the bottom of the food web. Students can investigate the impact of different trophic levels by including or excluding the consumers from the food chain and observing the impact on the temporal dynamics of the other species in the food chain. Students can flip back and forth between the current model run and the previous model run to examine the differences in model output.

Resources

The resource cycling module provides an opportunity for students to explore the interaction between biotic and abiotic factors in the rainforest. We originally planned the resources module as a culminating activity. However, in the early stages of planning, the resources module seemed out of place at the end. Instead, we decided that the resources module should come first as an analysis of the environmental context prior to analyzing the species reaction. The basic idea is to show an illustration of what the rainforest looked like before a hurricane, right after a hurricane, and then three years after a hurricane (see Figure 13 for a panel showing the illustrations).

For each time point, the student can examine water, carbon, and nitrogen resource cycles as overlays to the illustration (see example in Figure 14). Each component of the cycle overlays the illustration of that component. For example, the amount of carbon in plants is overlaid on a plant. The diagram shows the movement of a given resource during a specific time period. By moving the mouse over one of the colored labels, the system shows a graph of that data value over time (see the right panel of Figure 14). There is also a small triangle on the x-axis of the graph that shows the time period of the illustration to provide context for the given time point. By investigating the changes in resource cycling over time, students will have the opportunity to discover that there is a relationship between the biotic and abiotic factors.

One of the challenges in creating a coherent resource cycle diagram is that the scientific units for each component of a cycle are different. For example, rainfall is usually measured in mm/day, whereas stream flow is measured in cm^3/second. Fred Scatena reprocessed the historical record in El Yunque for all of our resource cycle data to come up with climatic averages that would all be in the same unit (e.g., for water everything was converted to mm/day).

During the beta test of the resource cycle module, we realized that even though the diagrams are static, they are extremely complex to interpret if students have not first studied the dynamics of the trees and animals. We ended up moving the resources module back to the end of the program to serve as a culminating activity.

We systemically developed the illustrations for the resources module so that they would maintain their coherence to the other modules in the program. Table 3 shows the textual description of what elements would be represented in each time period so that the components of the drawing would be authentic to what the environment is like. We hired a children's book illustrator, Robert Casilla, to create the rainforest drawings. Casilla developed pencil drawings by hand to represent the ideas in the chart (see Figure 15). After several

ELEMENT	3 MONTHS BEFORE	3 DAYS AFTER	3 YEARS AFTER
Trees	The forest is dominated by tabonuco, with a few yagrumo trees where gaps emerged from fallen trees. There are sierra palm on the stream banks.	The tabonuco and sierra palm mostly survive, but are stripped of their limbs/fronds. The yagrumo do not survive.	The forest is dominated by yagrumo at various stages of development, sierra palm have extended somewhat from the banks. The tabonuco are regrowing their limbs.
Canopy	Fully enclosed except over large stream	Completely defoliated, many broken branches and some broken trunks	Partially closed
Understory	Shadowed from canopy, mostly open space under trees, a few shrubs, leaf litter	Bright, filled with debris from hurricane	Partially shaded, lots of heliconia and piper
Sky	Partially cloudy	Clear	Partially cloudy
Consumers	A coqui and a walkingstick	A snail and mixture of green and brown anoles in the understory.	A caterpillar on a yagrumo and a brown anole. Mushrooms on a decomposed log.

TABLE 3. Table of conceptual elements to be included in the resource diagrams.

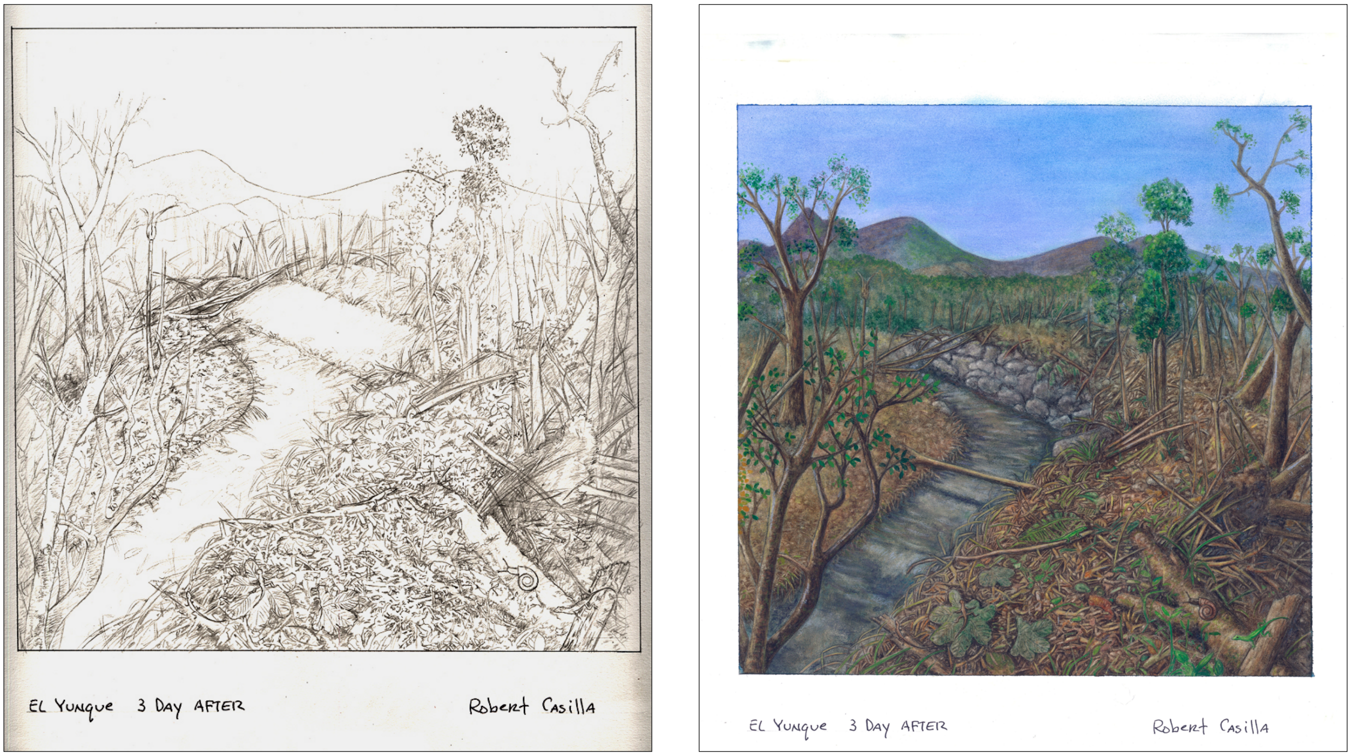

FIGURE 15. Interim drawings of the 3 days after illustration. Copyright 2006 by Robert Casilla. Used with Permission.

rounds of revision, we accepted the pencil drawings. Next, Casilla painted the pencil drawings with watercolor. Once Casilla finalized the watercolors, the paintings were scanned so that we could post them to the website.

Embedding the Science Standards within the El Yunque Community of Practice

Thus far, we have focused our discussion on how *Journey to El Yunque* provides students with an exposure to the El Yunque community of practice. Within each of the modules, the activities provide opportunities for teachers to authentically assess student learning as they engage in authentic scientific practices. However, to gain traction in schools, *Journey to El Yunque* has to address national science standards and support student achievement on standardized assessments. Therefore, a program based on the cognitive apprenticeship framework must also focus on content that schools deem to be important, while keeping students focused on the pursuit of the goals of the community of practice.

National and state standards provide a mechanism for emphasizing those aspects of authentic practice that relate to the basic knowledge that students will need for high stakes assessments. When the development of *Journey to El Yunque* program was initially funded in 2000, there were two predominant national standards: *National Science Education Standards* (NSES) published by National Research Council (1996) and *Benchmarks for Scientific Literacy* (BSL) published by American Association for the Advancement of Science (1993). These standards provided guidance on important ideas that should be emphasized through the investigation of hurricane disturbance in El Yunque. Another significant source of important ideas to emphasize came from textbooks published by the major publishers at the time (e.g., Addison-Wesley, Glencoe/McGraw Hill, Prentice-Hall). We sought to highlight those vocabulary words from the textbooks in places where those vocabulary words came up in the investigations.

Summative Evaluation Results

In the summative evaluation, we sought to collect evidence that *Journey to El Yunque* could help students on the types of high stakes assessments that schools deemed important. Researchers at The Center for Technology in Learning at SRI International conducted the independent evaluation of the *Journey to El Yunque* project (DeBarger & Haertel, 2006). The evaluation primarily focused on "the extent to which the *Journey to El Yunque* curriculum increases students' content understanding and scientific inquiry abilities." We measured these learning outcomes using the kinds of paper-pencil assessment questions that are prevalent on state tests. We recruited four pairs of teachers to participate in an evaluation of the program. Each pair of teachers taught the same kinds of students at the same school. Teachers signed a commitment letter indicating their willingness to participate in either condition. Using a coin flip, we assigned one member of the pair to the treatment condition and the other to the business-as-usual control. We provided the treatment teachers with training on the use of *Journey to El Yunque*. The control group teachers taught ecology at the same time as their paired treatment teachers using the activities they normally used. We provided the control teachers with training on *Journey to El Yunque* during the summer following the evaluation.

Since we designed *Journey to El Yunque* to address all of the middle school ecology standards, we measured student learning using a test of ecology knowledge developed from publicly released high stakes test questions on ecology. This strategy ensures that the content covered on the test is consistent with the content covered on high stakes assessments, but provides the flexibility and precision to detect differences that might exist between *Journey to El Yunque* and the control implementations. In addition to the assessment of ecology knowledge, students were asked to report on their perceptions of their experience with either *Journey to El Yunque* or their teacher's ecology unit.

Overall, SRI's analyses showed that students who participated in the *Journey to El Yunque* curriculum learned more ecology, based on the total posttest score, than students in typical ecology classes. The effect size in the study was 0.2, a small effect. Based on the attitudinal survey, students in both *Journey to El Yunque* and the typical ecology classes felt that the level of challenge, perceived success, and fun was about average (roughly 3 on a 1 to 5 scale), with students in the typical classes feeling a little more challenged and slightly more fun (0.2 effect size). These attitudinal findings are consistent with prior research showing that novel, inquiry-based environments can be disconcerting to students (Howard, McGee, Hong, & Shia, 2001). More work needs to be done on finding the optimal levels of challenge and success, which is what creates the feelings of fun (Csikszentmihalyi, 1991).

FUTURE DIRECTIONS

The Next Generation Science Standards (NGSS), which replaces the NSES as the new set of national science standards, were released in 2013 (NGSS Lead States, 2013). NGSS recommends a narrower scope, focusing on core disciplinary ideas. In addition, NGSS strengthens the emphasis on using scientific practices to investigate the disciplinary core ideas. We have been analyzing the relationship of *Journey to El Yunque* to NGSS. Even though *Journey to El Yunque* was released several years before NGSS, we feel that the program has a strong alignment to the NGSS ecology performance expectations. By anchoring *Journey to El Yunque* in the context of a scientific community, we ensured that the content focus would be on core disciplinary ideas and that students would be engaging with important scientific practices. However, the NGSS also highlights areas where the program could be improved, such as providing support for constructing arguments from evidence.

There are four areas where we seek to improve *Journey to El Yunque*.

1. **LEARNING AND INTEREST.** Students showed statistically significant increases in standards-based learning outcomes. However, they still struggle to engage in the scientific practice of generating explanations from the modeling activity. In addition, there is more we need to learn about how to motivate and sustain student interest in the investigation. Future research will examine how to best structure learning activities that are stimulating to students as well as provide adequate support and challenge for students to grow in scientific practices.
2. **MODELS.** Students are able to manipulate only the starting conditions of the limiting factors in the model. However, these limiting factors also change over time. We will provide a mechanism for students to see graphs of these limiting factors over time. In addition, we would like to be able to allow students to manipulate not just the starting condition, but also how those limiting factors change over time
3. **RESOURCES.** We would like to make the resources module dynamic. This would allow students to explore "what-if" scenarios and see the impact. For example, Puerto Rico recently experienced a severe drought in 2015. Students could alter the amount of rainfall in a dynamic resources module and see how that would impact the water cycle overall. In addition, the students would be able to see how the drought also affected the carbon and nitrogen cycles as well.
4. **HTML 5.** The current website is based on Flash to create the interactivity over the Internet. However, Flash is incompatible with many of the newer tablet computers. The website and models will be converted to HTML 5.

CONCLUSION

Journey to El Yunque represents a rare example of a learning environment that attempts to engage students with a specific community of practice. As we have documented, challenges arise from the tension between the research priorities of the community and pedagogical priorities of helping students engage in authentic scientific practice. Scientists are able to represent relationships between components in an abstract way. Therefore, their research prioritized investigating the temporal dynamics of the ecosystem. However, students need concrete representations of the relationships between components of the ecosystem coupled with concrete representations of the temporal dynamics.

Through the various modules within *Journey to El Yunque*, we have taken different approaches to building coherence between the temporal components and the spatial relationships in El Yunque. The payoff is that we have been able to create an environment in which students investigate a core ecological question using authentic scientific practices and students learn as much as or more of the science content that schools deem to be important. Future enhancements to *Journey to El Yunque* will continue to strengthen the ways the program can instantiate Dewey's philosophy of helping students develop the core ideas of a discipline by first helping them develop an emotional connection to the community of practice.

The development of *Journey to El Yunque* also represents a rare example of a long-term relationship between a life scientist and a learning scientist. There are several key ingredients that we feel contributed to the success of our partnership. At the time we started *Journey to El Yunque*, the Long-Term Ecological Research network was beginning its third decade and had been placing a greater emphasis on communicating the results of LTER research through education and outreach (Willig & Walker, in press). This expectation of LTER sites to become involved in education created space for Zimmerman to join me in making a long-term commitment to the development of *Journey to El Yunque*. Early on, Zimmerman invited me to become a member of the Luquillo LTER community, which readily accepted me as an insider. I became a co-Principal Investigator of the Luquillo LTER and Zimmerman has served as co-Principal Investigator on the *Journey to El Yunque* grants. Serving as co-PIs on each other's projects created a relationship of equals.

Through our working relationship, we developed a level of trust in the other's expertise, without fully understanding each other's fields. There was commonality in our core methodologies related to experimental design and statistics. This commonality in research language provided a foundation for developing an understanding of each other's fields. In addition, the process of development forced Zimmerman to distill complex processes to the important key concepts, which facilitated my understanding of forest dynamics in El Yunque. As I led the instantiation of these key concepts in curriculum designs, Zimmerman developed a concrete understanding of effective educational practices. The strength of our relationship provided a foundation for productively managing the design tradeoffs that has led to successfully taking students on a virtual *Journey to El Yunque*.

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REFERENCES

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy*. New York, NY: Oxford University Press.

Aronson, E., & Patnoe, S. (2011). *Cooperation in the classroom: The jigsaw method*. London, UK: Pinter & Martin Ltd.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32-42. http://dx.doi.org/10.3102/0013189x018001032

Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Carlson, J., Westbrook, A., & Landes, N. (2006). *The BSCS 5E instructional model: Origins, effectiveness, and applications*. BSCS. Colorado Springs, CO. Retrieved from http://bscs.org/sites/default/files/_media/about/downloads/BSCS_5E_Full_Report.pdf

Cohen, E. G. (1994). Restructuring the classroom: Conditions for productive small groups. *Review of Educational Research, 64*(1), 1-35. http://dx.doi.org/10.2307/1170744

Collins, A., Brown, J. S., & Newman, S. (1989). Cognitive apprenticeship: Teaching the crafts of reading, writing, and mathematics. In L. Resnick (Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser* (pp. 453-494). Hillsdale, NJ: Lawrence Erlbaum Associates.

Csikszentmihalyi, M. (1991). *Flow: The Psychology of optimal experience*. New York, NY: HarperPerrenial.

DeBarger, A. H., & Haertel, G. (2006). *Evaluation of journey to El Yunque. Final report*. Menlo Park, CA: SRI International. Retrieved from http://www.lponline.net/papers.html.

Dewey, J. (1916). *Democracy and Education*. New York, NY: Macmillan Company.

Hannon, B., & Ruth, M. (1999). *Modeling dynamic biological systems.* New York, NY: Springer.

Howard, B. C., McGee, S., Hong, N. S., & Shia, R. (2001). The Triarchic theory of intelligence and computer-based inquiry learning. *Educational Technology Research & Development, 49*(4), 51-71.

Lawson, A. E. (1989). *A theory of instruction: Using the learning cycle to teach science concepts and thinking skills*. NARST Monograph, Number One.

McGee, S., Durik, A. M., & Zimmerman, J. K. (2015, April). *The impact of text genre on science learning in an authentic science learning environment*. Paper presented at the National Association of Research in Science Teaching, Chicago, IL.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academies Press.

NGSS Lead States. (2013). *Next generation Science standards: For states, by states*. Washington, DC: The National Academies Press.

Reagan, D. P., & Waide, R. B. (Eds.). (1996). *The food web of a tropical rainforest*. Chicago, IL: University of Chicago Press.

Ripley, A. (2004, March 1). Beating the bubble test: How one Iowa school became a No Child Left Behind success story—and what it cost to do it. *Time Magazine, 163,* 52-53

Robinson, K. (1997). *Where dwarfs reign: A tropical rain forest in Puerto Rico*. Rio Piedras, PR: La Editorial Universidad de Puerto Rico.

Sfard, A. (1998). On two metaphors for learning and the dangers of choosing just one. *Educational Researcher, 27*(2), 4-13. http://dx.doi.org/10.3102/0013189x027002004

Shin, N., & McGee, S. (2003a). A research question should pique students' curiosity. In S. McGee (Ed.), *Virtual design center: Designing for the next generation*. Wheeling, WV: Center for Educational Technologies. Retrieved from http://vdc.cet.edu/entries/motivation.htm

Shin, N., & McGee, S. (2003b). A research question should spark students' ideas about the answer. In S. McGee (Ed.), *Virtual design center: Designing for the next generation*. Wheeling, WV: Center for Educational Technologies. Retrieved from http://vdc.cet.edu/entries/prior.htm

Stewart, M. M., & Woolbright, L. L. (1996). Amphibians. In D. P. Reagan & R. B. Waide (Eds.), *The food web of a tropical rainforest*. Chicago, IL: University of Chicago Press.

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction, 4*(4), 295-312. http://dx.doi.org/10.1016/0959-4752(94)90003-5

Waide, R. B., Comarazamy, D. E., González, J. E., Hall, C.A., Lugo, A.E., Luvall, J.C., … Silver, W. L. (2013). Climate variability at multiple spatial and temporal scales in the Luquillo Mountains, Puerto Rico. *Ecological Bulletins, 54*, 21-41.

Willig, M. R., & Walker, L. A. (in press). Changing the nature of scientists: Participation In The long-term ecological research program. In M. R. Willig & L. A. Walker (Eds.), *Long-term ecological research: Changing the nature of scientists*. New York, NY: Oxford University Press.