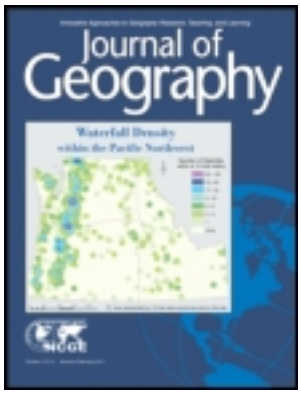

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Collaborative Learning and Global Education: Human-Environment Interactions in the Galápagos Islands, Ecuador

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Collaborative Learning and Global Education: Human–Environment Interactions in the Galápagos Islands, Ecuador

Laura Brewington, Kim Engie, Stephen J. Walsh, and Carlos Mena

Abstract

This article focuses on two innovative approaches to teaching human–environment interactions and international engagement in geography: (1) utilization of an agent-based model (ABM) at undergraduate levels to explicitly demonstrate complexity theories, and (2) implementation of a teaching experiment that connects students simultaneously enrolled in companion courses in North Carolina and in the Galápagos Islands through various multimedia and synthetic approaches to enrich a case study of conservation challenges to a World Heritage Site. Spatial simulation models are used to complement integrative geographic learning, to demand higher order skills of students and build critical thinking in college classes.

Key Words: *Galápagos Islands, human–environment interactions, agent-based model, scenario testing, student engagement*

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Introduction

While globalization is not a new phenomenon, it is posing new challenges to humans and natural ecosystems in the twenty-first century (Leichenko and O'Brien 2008). From climate change to increasingly mobile human populations to the global economy, the relationship between humans and their environment is being modified in ways that will have long-term impacts on the sustainability of sensitive and fragile environments (Beck 2000; Adger *et al.* 2003; O'Brien *et al.* 2004; Turner *et al.* 2003; Aggarwal 2006; Polsky, Neff, and Yarnal 2007). These challenges are perhaps nowhere more evident than in island ecosystems, including the Galápagos Islands of Ecuador (Barnett 2001; Kerr 2005). Buffeted by rising ocean temperatures, extreme weather events and climate change, and besieged by a growing demand for access to special places by a burgeoning international tourism market, islands represent great vulnerability to globalization and also a scientific opportunity to study the impacts and significance of global changes within coupled human-natural systems.

The Galápagos Islands provide a particularly strong illustration of the challenges associated with resource conservation and economic development in island settings. During the past three decades, dramatic changes have threatened the continued vitality of the island's social, terrestrial, and marine subsystems so that both social and ecological sustainability are in question. Recognizing these threats, from June 2007 to July 2010 the United Nations Educational, Scientific and Cultural Organization (UNESCO) declared the Galápagos Archipelago an endangered World Heritage Site, and similarly, the Ecuadorian Government declared an "ecological emergency" for the islands (Watkins and Cruz 2007; UNESCO 2010).

Beginning in the 1970s, the archipelago has experienced exponential population growth and corresponding economic development to support the burgeoning tourism industry. Thousands of new residents began to migrate from the mainland of Ecuador, attracted by the promise of lucrative opportunities linked to the islands' rich marine and terrestrial ecosystems and the lack of economic opportunities in many parts of the mainland (Borja 2003; Kerr, Cardenas, and Hendy 2004). The fast-paced development of the tourism industry contributed to the growth of the local population, from under 10,000 in 1990 to nearly 23,000 residents today (Instituto Nacionál de Estadistica y Censos 2010). However, estimates suggest the human population is nearer to 28,000, as illegal migration, primarily from the Ecuadorian mainland, continues to be a problem of concern in the Galápagos Islands. In addition to settlement and population immigration, the number of tourist visitors has increased from 41,000 in 1990 to nearly 185,000 today (Galápagos National Park Service 2011).

Some of the more pronounced social-ecological effects associated with the increased human presence in the islands include unprecedented use and extraction of terrestrial and marine resources; introduction and proliferation of invasive flora and fauna; unprecedented energy consumption and waste generation; exploitation of local fisheries and industrial fishing adjoining reserve borders; and increased interinstitutional conflicts over governance and policy (Watkins and Cruz 2007). The contentious vote of the World Heritage Committee, which removed the Galápagos Islands from the at risk list of World Heritage Sites in July 2010 (UNESCO 2010), signaled that much remains to be done to reduce the direct and indirect impacts of the expanding human imprint on the archipelago.

Mindful of this close coupling of humans and environment, a new undergraduate course, Population-Environment Interactions in the Galápagos Islands, has been developed in the Department of Geography at the University of North Carolina at Chapel Hill (UNC) to examine these and other linked human–environment issues through interdisciplinary perspectives. The goal of this article is to describe the central elements of the course, and how its emphasis on hands-on experience with mixed methods (critical thinking and writing, data integration, agent-based models, and computer simulations), real-time engagement with the Galápagos community, and integrative theories contribute to education from a global context.

Approaches to International Geographic Learning

As geographers with expertise in measuring and modeling social, spatial, and ecological processes, the authors' teaching perspectives draw from extensive field research in the archipelago that has been conducted as part of a broader, multiuniversity research initiative. The instructors and teaching assistants have engaged with subfields in geography that focus on environmental change, population migration and tourism, invasive species, fisheries, and their linkages to resource conservation and economic development. They have employed methods in spatial analysis, GIS, and remote sensing to study land cover change, surveys, and qualitative methods to study environmental politics and social change, statistical models to examine demographic data, and spatial-computational modeling to explore the specific mechanisms and implications of selected human–environment interactions involving the social, terrestrial, and marine subsystems. These correspond to interdisciplinary literatures such as Coupled Human and Natural Systems (CHANS), Land Change Science, Ecological Systems Modeling, Demography and Population Migration, and Complex Adaptive Systems.

Particular approaches to the study of how humans shape their environment, and, in turn, how the environment shapes human behavior, have been formed through these research pathways, and are put forth here as a useful complement to the educational framework employed by others who emphasize a developmentalist framework; that is, the application of development studies to regions perceived as undeveloped from a Global North perspective. Human geography in particular, with its emphasis on the place-based nature of economic or subsistence activities allows these regions to be "understood in new ways, not simply in terms of what they are not or what they are expected to become vis-à-vis the core" (McFarlane 2006; Murphy 2007). The authors argue that the use of case studies of economic, social, and spatial change within the Global South and modeling scenarios in the classroom provides students with complementary alternatives that promote students' understandings of a dynamic world view (Williams, Meth, and Willis 2009; Breen 2012). By considering the emergence of those relationships within a complex system, specific challenges to development and change (such as resource depletion, political shifts, or migration) can be visualized in an active, rather than passive, format.

The course described in this article is designed to integrate theories and practices from across the social, natural, spatial, and computational sciences to examine the contested issues related to resource conservation and economic development of the Galápagos Islands. UNC students, in the traditional classroom setting on the UNC-Chapel Hill campus in North Carolina, receive a strong ecological, geological, and biological background on the islands. They are also exposed, many for the first time, to the lesser-known human history and contemporary development issues facing the archipelago, with a focus on the central employment sectors in the Galápagos: agriculture, fisheries, and tourism. Essential ingredients of the course include the incorporation of a collaborative and transnational discourse achieved through (1) a partnership with Ecuadorian faculty and students at the Universidad San Francisco de Quito (USFQ)'s undergraduate teaching facility, GAIAS (Galápagos Academic Institute for the Arts and Sciences) on San Cristóbal in the Galápagos Islands; (2) the engagement of research, education, and community outreach on the ground at a facility recently dedicated on San Cristóbal Island; and (3) integration of students to ongoing research via in-person visits with international researchers and the use of their scientific papers and reports in class. These outlets provide UNC and USFQ students with a local presence in the Galápagos Islands and an opportunity to draw upon diverse perspectives about resources, programs, and policies as told by local merchants, tourists, farmers, fishers, politicians, and other stakeholders.

Contemporary Interdisciplinary Education

There have been considerable changes in the American social and educational systems throughout the last twenty years that impact the design of this course and the engagement of local students with distant peers, content delivery, and the discovery and synthesis of knowledge through multimedia and hands-on approaches. The rise of social media and the increasing complexity and intertwined nature of many pressing global issues demand attention in educational curricula. With the widespread impact and access of online forums such as Facebook and Twitter, a blend or hybrid of physical and virtual learning environments can further enhance teaching and student engagement and satisfaction, while attenuating geographic barriers to learning and understanding (Graham 2006; McCarthy 2010; Wu, Tennyson, and Hsia 2010). Applied learning approaches are being incorporated into curricula in a variety of fields, including health sciences (Ibrahim, House, and Levine 2001; Cashman and Seifer 2008; Florence and Behringer 2011) and architecture/engineering (Chan

et al. 2002; Dederichs, Karlshoj, and Hertz 2011). Geography has emerged as an interdisciplinary field that integrates cross cutting technologies with arts and sciences education (Murphy 2007; Taylor 2009), particularly with respect to studies of conservation and sustainability science (Jacobson and Robinson 1990; Turner 2002; Clark 2007; Nation 2008).

Problem-solving and cognitive skills are increasingly sought in modern research and technology-driven industries (Pink 2006; Williamson 2011), making learning experiences that incorporate real world and contested scenarios essential to postsecondary education. This move away from traditional lecture methods in the university setting has been met with positive results in the classroom and in educational psychology research (Zhang 2002, Zhang and Sternberg 2002). Conflicts around resource conservation and economic development choices in the Galápagos Islands are a salient example of how global concerns over sustainability are being played out in real-time, and with serious implications, for local residents and international NGOs. Cultivating responsible global citizens in the midst of continual information saturation and politically oriented news outlets points to a strong need for critical thinking and information synthesis on complex issues.

Although there is no consensus on how to define *critical thinking*, general agreement is that skills common to the ability to think critically include reasoning, generating hypotheses, inferring arguments based on available data and evidence (e.g., Halpern 1993; Terenzini *et al.* 1995), and in general "applying, analyzing, synthesizing and evaluating information..." (National Center for Excellence in Critical Thinking Instruction, 1991). A recent study following an entire cohort of students from the beginning of college through four years found that 45 percent showed no significant improvement in critical thinking skills, including the ability to discern information from political spin and emotional testimony (Arum and Roksa 2011; Rimer 2011). One approach to helping confront this education challenge is to move students away from linear-thinking by embracing theories and practices that address dynamic and nonlinear systems, which can also promote abilities to recognize multiple perspectives (Walsh, McCleary *et al.* 2008).

The application of complex systems theories is a relatively recent approach to examining the integrative nature of humans and the natural environment. Coupled nature-society perspectives often shape international conservation initiatives in developing countries such as Ecuador, and potential development pathways are contingent on environmental change and the choices made by citizens, institutions, and governments. Rapidly changing the way that research is approached across geography (Manson 2001; Michener *et al.* 2001), ecology (Levin 1998; Holling 2001), and the humanities (Thrift 1999; Massey 2005), these theories represent an opposing avenue for knowledge production of "cause and effect" social and ecological relations compared to traditional experimental science, even while sharing quantitative and computational dispositions. Complexity theories conceive the world as consisting of self-organized systems, either reproducing their state through negative feedbacks with their environment, or moving along trajectories from one state to another as a result of positive feedbacks. Complex systems not only evolve through time, but their past is co-responsible for their present behavior (Levin 1998; Walsh, Messina *et al.* 2008). In addition, concepts such as social-ecological coevolution, adaptation, and resilience can be utilized to study the way that humans and ecosystems interact (Mena *et al.* 2011; Walsh *et al.* 2011). This view sees the complex nature of systems as emerging from nonlinearities due to large numbers of interactions involving feedbacks occurring at lower levels within a system (Malanson, Zeng, and Walsh 2006). Importantly, complex adaptive systems do *not* imply that human and ecological systems are in equilibrium—the very disequilibrial and constantly changing relationships help propel nonlinear dynamics.

Innovative methodologies and nonlinear mathematics have enabled the operationalization through computer models of theories of nonlinearity, multiple stable states, adaptive behaviors, and historical legacies on complex problems (e.g., Michener *et al.* 2001; Manson 2001; May, Levin, and Sugihara 2008). One of the most prominent of these methodologies is the agent-based model (ABM), a quantitative technique explicitly developed to model entities (i.e., humans) that change (rather than being identical and constant) and nonlinear interactions among them (rather than assuming independence among variables), which violate traditional statistical assumptions (Manson 2001). ABMs are used to harness the potential of computational models to explore the insights possible by integrating disparate facts, while reflecting more realistic assumptions about how entities interact in a complex world. Some major research areas where they have become prominent include many CHANS processes that span social and natural interactions such as land use change (e.g., Parker *et al.* 2003; Entwisle *et al.* 2008), water management scenarios (Castella *et al.* 2005), and fishing strategies (Little and McDonald 2007; Cabral *et al.* 2010). They are also being used across disciplines such as sociology and political science to model human decision-making processes, such as cooperation in collective action dilemmas (Poteete, Janssen, and Ostrom 2010; An 2011) and enrollment in conservation programs (Sengupta *et al.* 2005).

Despite enormous growth in active research, however, the transference of such approaches to education is thus far quite small, although complex systems are beginning to be introduced into classrooms and science curricula (e.g., Erlien *et al.* 2006, Hmelo, Holton, and Kolodner 2000; Walsh *et al.* 2009). Teaching such ideas and methods to educational levels below graduate school can accompany traditional science curricula, and greater incorporation into college-level education is an opportunity for tertiary student development of critical thinking and synthesis skills (Jacobson and Wilensky 2006). One of the most accessible ABM platforms specifically directed at educational uses

is Netlogo,[1] an open-source, fully customizable model platform using Java software and developed by the Center for Connected Learning and Computer-Based Modeling (CCL) at Northwestern University. Although Netlogo is a popular tool in academic research, it was also developed to specifically help promote ". . . the creative use of technology to deepen learning" and has an active user community that disseminates ABMs developed to support various curricula (e.g., Levy and Wilensky 2009; Blikstein and Wilensky 2010).

This article focuses on two innovative approaches to learning and international engagement. The first is the engagement of college students with ABMs as a specific analytic tool to teach complex systems approaches, with an emphasis on social-ecological interactions in the Galápagos Islands. The second approach is a teaching and learning experiment virtually connecting students enrolled at UNC with peers enrolled in a similar course taught at USFQ's teaching facility GAIAS on San Cristobal Island in the archipelago.

Case Study: Human–Environment Interactions in the Galápagos Islands

The Galápagos Islands are well known as a living laboratory for the study of evolution and global environmental change, and also for heightened conflicts between nature and society (e.g., MacDonald 1997; Quiroga 2009). Unlike another archipelago similar in geologic age, the U.S. Hawaiian Islands, the Galápagos do not possess an indigenous human population and were uninhabited prior to their accidental discovery in 1535. Free of humans and predators for almost all of its history, some of the most unique life forms on the planet have developed in Galápagos, highly adapted to their harsh surroundings and living in ecological isolation from the rest of the world. It was not until Charles Darwin's famous visit in 1835, which helped inspire the theory of evolution by natural selection, that the islands began to receive international recognition (Stewart *et al.* 2007). In 1959 the Galápagos National Park was formed, and in 1973 the archipelago was incorporated as the twenty-second province of Ecuador. UNESCO designated the Galápagos Islands as one of the first World Heritage Sites in 1978 under all four natural criteria, and later inscribed them as a Man and the Biosphere Reserve in 1984 (UNESCO 2006). The Galápagos Marine Reserve, first established in 1986, was more than doubled in size in 1998 to extend 40 nautical miles (133,000 km^2) from a baseline around the islands, and today it is the fourth largest reserve in the world. The archipelago is made up of fourteen large islands and two hundred small islands totaling 8,010 sq. km., about the size of the State of Delaware, USA (Figure 1).

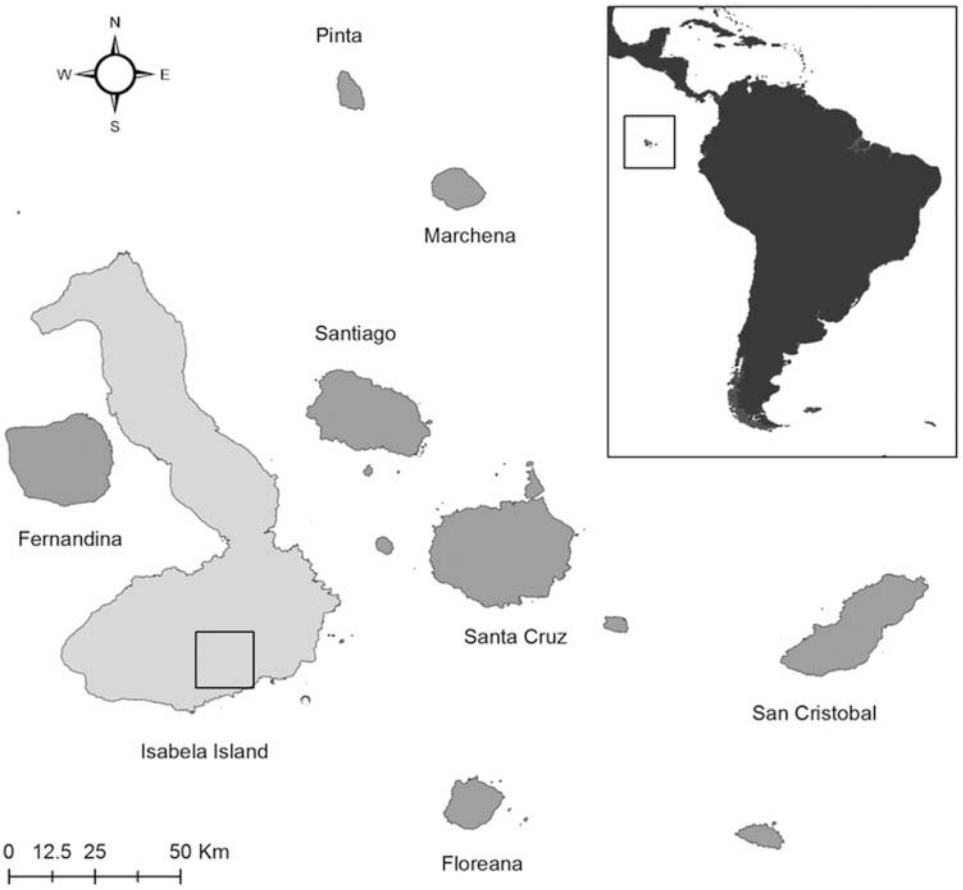

Figure 1. The central Galápagos Archipelago of Ecuador and the modeled area on Isabela Island.

The Galápagos Islands provide a unique opportunity to study complex interplays of social, terrestrial, and marine subsystems. Throughout the course, students study a diverse set of social and ecological changes that influence human–environment interactions in the Galápagos Islands, including: (1) global climate and the attendant changes in resource stocks and flows, weather patterns, and land use; (2) new flows of tourists, population migration, and endogenous population growth on mainland Ecuador; (3) the development of global markets for

marine resources, tourism, and the marketing of the island's agricultural products; (4) the spread or eradication of invasive flora and fauna and their influence on native and endemic species; and (5) coastal processes, the maintenance of mangrove forests, marine ecology, and El Niño events on marine productivity.

Within this context, students are confronted with a number of questions that link the social, terrestrial, and marine subsystems and underscore the need to assess overall sustainability of the Galápagos Islands in multifaceted ways:

- How can economic development and resource conservation be reconciled in the Galápagos, and how can social and ecological systems adapt, leading to sustainability?
- What are the impacts of climate change on the behavioral shifts and adaptive capacities of the social, terrestrial, and marine systems?
- How can continued growth of tourism and population migration occur without degrading the environment and further diminishing the characteristics that draw international tourists and global attention to the Galápagos?
- How do invasive flora and fauna affect land use/land cover patterns and ecosystem goods and services? How is farm productivity degraded by invasive species, while being connected to food security and constituting a viable livelihood alternative?
- How can changes in El Niño and/or the Pacific Decadal Oscillation events influence social-ecological interactions and the sustainability of the Galápagos?
- What are the social and ecological forces that drive fisheries activity, and how do shifts in habitat, population, and human use dynamics affect the use of fisheries as a viable household livelihood?

The UNC Galápagos course is divided into four units that apply a variety of formats and approaches:

1. *Living Laboratory—Galápagos Islands and Social-Ecological Contexts*: The first unit introduces students to the Galápagos archipelago and focuses on developing its biophysical background and discovery by the Western world, Charles Darwin's voyage to the islands and his subsequent theories of evolution, and the unique terrestrial and marine life that has captivated scientists for over 200 years. In-class discussions of an introductory textbook (Stewart *et al.* 2007) and a linked Galápagos-BBC video-documentary, journal articles, and classroom activities engage students in the historical connections between Galápagos Island inhabitants and the environment.
2. *Plundering Paradise—Galápagos at the Crossroads*: The second unit focuses on readings related to the idea that Galápagos is "at a crossroads" (Bassett 2009), covering contemporary issues such as environmental degradation and resource extraction by the islands' human visitors and inhabitants, changing economic conditions and livelihoods, the institutional history of the archipelago, social unrest, and the politics inherent in environmental protection.
3. *Integration of Social, Terrestrial, and Marine Subsystems in the Galápagos Islands—The Science of Coupled Human-Natural Systems:* In the third unit students are exposed to selected journal articles on complexity theory and nonlinear systems, and observe a series of video documentaries and multimedia productions that tell the story of people and environment in the Galápagos Islands.
4. *Moving Forward—Scenarios of Resource Conservation and Economic Development in the Galápagos Islands:* In the fourth unit students focus on developing case-based scenarios of development, livelihoods, and land-use changes using an ABM created to represent Isabela Island (Miller *et al.* 2010), and linked to complexity theory (Gonzalez *et al.* 2008).

Throughout the course, guest speakers, interviews of Galápagos residents and visitors to the islands, and an ABM exercise are integrated within the classroom experience, blending teaching methods and content. Teaching was structured in a way to promote critical thinking while allowing for a mixture of individual and group learning arenas (Arum and Roksa 2011). While in-class discussions and readings facilitated understanding of conservation issues as a group, short papers stressed individual work. In them students had to show an understanding of the *processes* behind their chosen subject; typically an issue containing a contradiction among how various elements of the islands are treated (for example, trade-offs between human and ecosystem well-being). Also important was the ability to show knowledge of counterarguments, for whom and by whom benefits and costs accrued. Ethical writing standards through proper citation, use of primary sources, and training on plagiarism were also a major course emphasis. Fully 25 percent of a student's grade hinged upon synthesis, and another 13 percent upon proper citation.

Collaborative Learning and Global Education

Each fall a course called Human Ecology of the Galápagos Islands is taught at GAIAS, the USFQ undergraduate teaching facility in the Galápagos Islands. At the same time, students at UNC enroll in Population-Environment Interactions in the Galápagos Islands that is taught in a more traditional classroom setting. A cross-institutional engagement between UNC and USFQ facilitates a dialogue between students enrolled in each class, and faculty who collaborate in the Galápagos. During the 2010 and 2011 semesters at USFQ, students were a mix of national and international students from the Galápagos Islands, mainland Ecuador, as well as students from the USA and Western Europe. With educational backgrounds in tourism, terrestrial ecology, and marine ecology, the students had

Table 1. Sample interview questions that framed student inquiry and interviews with local residents in the Galápagos Islands.

Stakeholder Group	Interview Topics	Sample Questions
Any residents	General life in a National Park & Marine Reserve	Do you think that environmental conservation is valued differently than economic stability for inhabitants in the Galápagos? To what extent do you feel connected to or disconnected from the other islands or the mainland?
Farmers, members of agricultural industries, conservation organizations, food vendors, and land managers	Agriculture and Invasive Species	How does tourism affect the highlands? How adequate do you think the current inspection and control systems or checkpoints are? *For Vendors*: Do you sell foods from San Cristobal or from the mainland at your food stand or restaurant? Do you think there is a strong local food economy?
Fishermen, boat operators, dive instructors	Fisheries and the Marine Environment	What are the difficulties about being a fisherman? How do you feel about the shift towards a tourism economy in the Galápagos?

some experience and academic training in the primary subsystems of the Galápagos. The UNC undergraduate Galápagos course intentionally supports a diverse student population from geography, international studies, political science, sociology, geological sciences, biology, and environmental studies.

The familiarity of the instructor and teaching assistants with the Galápagos Islands do not substitute for real-time engagement with local stakeholders and the environment in which they live, work, and generally interact. In the second and third course units, students at UNC are able to see and hear perspectives in the islands through the captured words and images of Galápagos residents, visitors, and professionals using videography and multimedia tools.

Students were exposed to live interactions with members of Galápagos society through two avenues: the opportunities to have face-to-face roundtable discussions with incoming Galápagos citizens, and Web-based social media. The 2010 UNC class benefited from the ability to hear directly from, and question, a panel of Galápagos residents and scientists who were attending a joint USFQ-UNC Galápagos research workshop in North Carolina. Panelists included one of the three municipal mayors in the islands and researchers working in diverse fields including anthropology, evolutionary biology, and fisheries. This class period was rated highly in student self-assessments. In Ecuador, engagement between classes is further illustrated by visits from UNC instructors during the semester to the Galápagos, enabling on-ground participation with USFQ students in the interview process in the Galápagos.

In addition to the panelist visits, students at UNC were able to indirectly interview residents in Galápagos through their counterparts at USFQ. UNC students developed a list of island stakeholders to guide interviews by the USFQ class in the Galápagos Islands. They did so after viewing *Living Galápagos*, an online documentary project[2] produced during the summer of 2009 by undergraduate students in the UNC School of Journalism and Mass Communication. Through short video clips and interactive media, the project described the unique people and places of the Galápagos Islands, and the contemporary challenges they face. Corresponding questions were developed for members of each stakeholder group and sent to the USFQ course instructor and students for comment.

For two weeks, USFQ students used handheld flip-video devices to document the interview process and to acquire stories from and about the islands by residents and visitors. Table 1 presents the types of questions developed for each identified stakeholder group in the Galápagos Islands that were used to frame the student interviews in the 2010 course. Because the interview component of the course was used for educational classroom purposes and not individual research or reporting activities, human-subjects research approval was not needed, as confirmed by the UNC and the USFQ Institutional Review Boards. However, in-class training on the need to consider ethics in human subjects was provided during the interview planning and execution phases, and USFQ students were directed to work within the UNC-generated areas of interest while avoiding lines of questioning that might invoke sensitive or personal responses. The video files were password protected and uploaded to a secure file server at UNC to which only course administrators had access.

The average duration of each interview was thirty minutes, and critical topics and themes emerged through the dialogue.[3] To facilitate student viewing, critique, and discussion of the videos, a Web-based video interface[4] was used to enroll all students as users. Instructors uploaded narrated slide shows from video clips to share with the class. Within this framework, students from UNC and USFQ were able to exchange ideas and perspectives through the shared

videos and documentaries with text, audio, or digital ink. By augmenting readings and discussions with these recorded interviews, students developed a synthetic understanding of the social and ecological interactions that occur in the Galápagos Islands. Nonetheless, the difficulty of executing such exercises in a compressed time frame of three weeks was apparent to both teachers and students, and this course element was conducted in 2010 but not in 2011.[5]

Modeling a Dynamic Human–Environment System

During the fourth and final unit of the course, classroom teaching is centered on using a complex systems approach to study these contemporary social-ecological challenges. A classroom assignment featuring an ABM has the intent of challenging students to think creatively, develop scenarios that are rooted in real dilemmas and supported by lectures, readings, and engagement with members of the community, and to examine hypothetical alternate futures of the Galápagos that demonstrate the linked effects of people and environment. In effect, students animate multiple perspectives about conservation and development in ABMs by setting in motion actions that represent various priorities.

ABM techniques were introduced through the NetLogo platform. Given that it was designed as an educational tool, NetLogo provides opportunities for engaging students in ABM modeling with a host of available online model examples that range in simplicity and often are accompanied by supporting documentation. Among the many social phenomena that have been developed into models for educators and released online by a large user community are cooperation, altruism, segregation, cocktail party dynamics, and traffic patterns. Many other processes in the physical sciences are modeled as well. Educators can choose a model centered on the process of interest for use in the classroom; this class utilized an ABM specifically parameterized for the Galápagos Islands, which was a byproduct of a previous graduate-level seminar at UNC and is known as ILLUM (Isabela Livelihoods and Land Use Model). This virtual environment was created to closely resemble Isabela Island, Galápagos (see Miller *et al.* 2010).

The ILLUM model examines the implications of alternate *household livelihood strategies* on the spread or eradication of invasive plant species, land use change, and economic development. Isabela Island is emphasized in the virtual model because it is poised for considerable change due to economic development to meet the needs of a burgeoning tourism industry, while attempting to not compromise resource conservation. As such, Isabela represents the transitions that other tourist destinations have undergone or will undergo, including other islands in the Galápagos, and protected areas more generally. There are concerns about decline in the management of invasive species in Isabela's highland agricultural zone and associated land abandonment, particularly in regions such as the 50 km^2 located along the slopes of the Sierra Negra Volcano. Because of the effort required to control invasive species on farms and the general lack of market integration for the sale of crops and agricultural products, the development and spread of invasive species could lead to farm abandonment and a move away from agriculture toward livelihoods in other employment sectors, mainly tourism. Decisions made by farming households in the highlands indirectly affect land in the surrounding Galápagos National Park. Cattle and horses routinely graze at the farm-park edge and also in abandoned farms. Through this and other pathways, invasive species escape from rural lands into protected areas where they have previously been eradicated or are newly established. Common guava (*Psidium guajava*), for example, is a shrub or small tree widely cultivated for its edible fruit (Ellshoff *et al.* 1995), and is Isabela's primary plant invader (Tye 2006; Walsh and McGinnis 2008). Guava was introduced into the Isabela highlands through the agricultural zone, which is completely surrounded by land that originally consisted of native Scalesia forests and the treeless fern-sedge zone (Hamann 1981).

ILLUM was designed to maintain the fundamental characteristics of the Galápagos Islands without incorporating needless definition and noise in the geographic setting and the modeling environment (Walsh *et al.* 2009). The spatial simulation integrates disparate social and ecological data, organized within a geographic information system, to examine interactions and feedbacks in an island setting. Guava agents, or GIS cells, change through neighborhood effects, while park guard agents eradicate guava and are free to move around the entire protected area. Other human agents accumulate wealth according to livelihood decisions and react to the consequences of environmental change (i.e., agricultural productivity and wages) following the conceptual framework presented in Figure 2. Students are given instructions to download the NetLogo software and to use the existing ILLUM model of the Galápagos. In addition to reading about the development and implementation of the ABM (Miller *et al.* 2010), simulations, documentation, and tutorials available on the NetLogo Web site are demonstrated in the classroom setting to familiarize students with the tools and capabilities of the programming environment.[6]

Although one of the primary outcomes of the model is the spread of the highly invasive plant, guava, instructors directed emphasis to how agents can switch livelihoods based on a number of inputs: expected number of tourists, number of open fishing licenses, selling price of fish and agricultural products, start-up costs, and costs of maintaining their property. A simple user-interface of sliders and buttons, map displays, and plotting utilities for model variables makes it relatively simple to examine the implications, for instance, of a doubling of tourism or a change in the frequency and/or magnitude of El Niño events on system behavior. Figure 3 shows the display template used to examine the movement of agents in the agricultural highlands and the surrounding protected area, the coastal community, and fisheries.

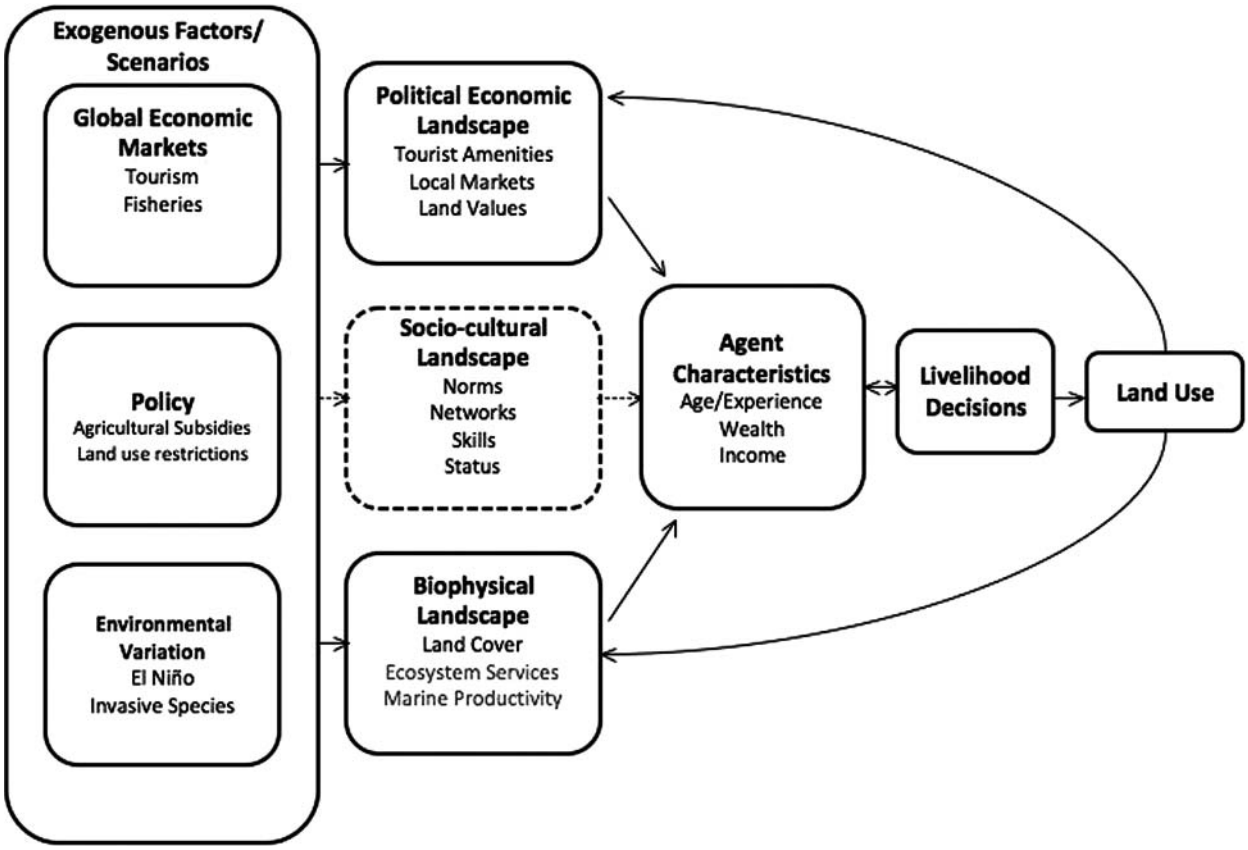

Figure 2. Conceptual framework for modeling livelihood decisions and land use/land cover processes in a virtual Galápagos Islands. (From Miller *et al.* 2010.)

Students used the options in the model to explore alternative scenarios twenty-five, fifty, and one hundred years into the future, running the model many times to investigate the impacts of altering various initial conditions and the convergence of outcomes. They interpreted their findings, social-ecological feedbacks, and future scenarios in their final class paper. They described why they chose the rules and characteristics of the agents in their model, and considered how likely these scenarios are and what they may imply for future management decisions, livelihood strategies, or environmental changes in the Galápagos Islands.

Student Accounts: Some Snapshots

While student learning could not be directly measured without a control group nor before-and-after student assessments, inferences were drawn through two avenues: an end-of-semester questionnaire asking for student feedback, and the four short writing assignments given through the class.

At the end of the 2010 and 2011 semesters, a survey was administered to gauge students' self-assessment of learning and satisfaction with the blend of lecture and technology-based teaching methods that are applied throughout the course. This survey was administered jointly by a center within the university that partially funded the video project and was influenced by, and has several questions adopted from, the National Survey of Student Engagement (NSSE). This section focuses on only those questions related to various teaching tools and student-rated importance to understanding. Student feedback noted that although many found the technology-driven tools useful, the majority of them felt that they benefited more from traditional classroom methods (Table 2). Lectures and reading assignments received the highest scores with respect to their importance in the learning environment, while videos, particularly Voicethread, were generally ranked as lower impact. Nonetheless, 80 percent and 89 percent of students rated the ABM exercise at least somewhat important to their understanding of overall course materials in 2010 and 2011.

First-Hand Instruction and Real-World Importance: Students responded favorably to the lectures and in-class discussion components of the course, particularly given that the instructor and teaching assistants all had extensive field knowledge of the Galápagos: "I appreciate the passion demonstrated for Galápagos," said one. By framing the course in the context of a contemporary environmental crisis in a World Heritage Site, students were able to relate

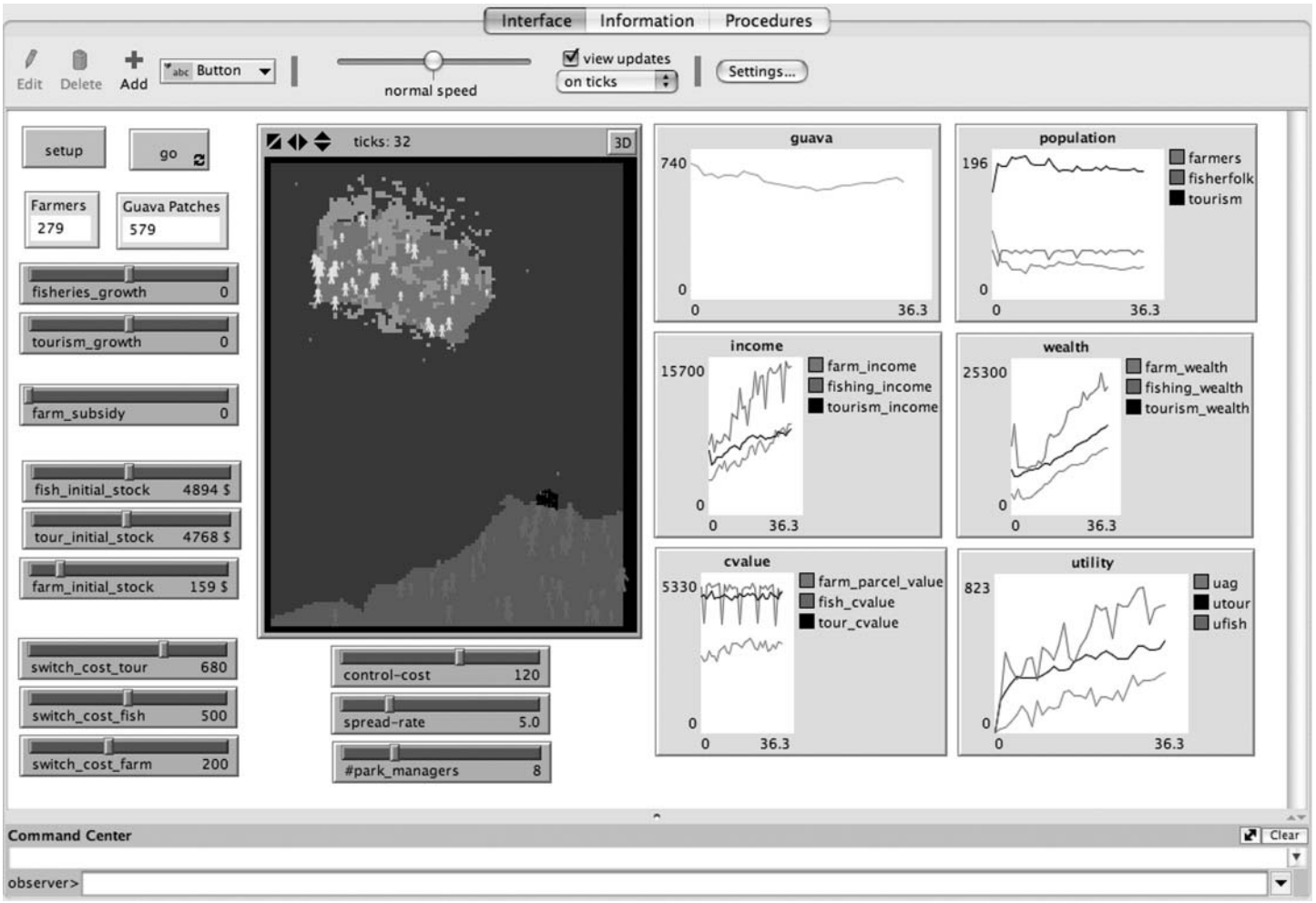

Figure 3. Agent-based model interface for engagement with the Galápagos spatial simulation model. Trend lines for each annual model iteration are displayed graphically, allowing students to visualize dynamic relationships over time and through space to enhance learning. (Adapted from Miller *et al.* 2010.)

the topics covered during lecture to a real-world setting, expressing sentiments such as, "I liked that it felt like a real-world application of classroom knowledge," and, "Very interesting material, had overall importance in the world."

Multimedia in the Classroom: The interviews and Living Galápagos videos were important to enhancing student understanding of course concepts and the perspectives of Galápagos Island residents on a more personal basis. "I liked to see things from the people of Galápagos' point of view," commented one student. Others expressed a clear preference for interactive learning over traditional class readings, as one said, "I did not like the whole learning from journals. It was dull."

North-South Dialogue: The compressed timeframe made it a challenge to fully integrate the interactions in the course and to efficiently process, edit, and upload videotaped interviews with stakeholders. Students still responded positively to "the way we could interact with people so far away," as one said. "I liked the idea of interviews with locals," said another, "It didn't turn out quite as well as hoped. But I think there is value there." One student from the course applied and was accepted to the first joint UNC-USFQ Study Abroad Program taught at GAIAS during summer 2011. In his words, "I am passionate about conservation, and took this opportunity to learn more."

ABM Scenario Testing: The NetLogo modeling exercise was less well received, and was given mixed rankings among students in the final survey. Interestingly in 2011 when there were also fewer multimedia teaching tools since the Voicethread component was removed, the percentage of students who rated the Netlogo model "important" or "very important" to their understanding of overall course materials rose. Student comments were mixed concerning the NetLogo modeling exercise. "It was tedious to get

Table 2. Student responses to survey questions about the importance of classroom components.

	Very Important		Important		Somewhat Important		Less Important		Least Important	
Survey Measure	**2010**[a]	**2011**[b]	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**[c]	**2010**	**2011**
Lectures	48%	40%	38%	36%	15%	20%	0%		0%	4%
In-class discussions	5%	7%	33%	33%	45%	44%	18%		0%	16%
Guest speakers	3%	0%	53%	16%	38%	44%	5%		3%	22%
Readings	40%	36%	45%	44%	15%	13%	0%		0%	0%
VoiceThread[d]	5%		28%		60%		5%		3%	
Living Galápagos	18%	9%	48%	47%	35%	38%	0%		0%	7%
NetLogo model	0%	7%	20%	29%	60%	53%	20%		0%	13%
Paper assignments	15%	29%	64%	44%	18%	22%	2.6%		0%	4%

a: in 2010, N = 40.
b: in 2011, N = 45.
c: in 2011, "less important" was not a category on the exit exam.
d: in 2011, VoiceThread was not utilized.

[NetLogo] to work properly (though it did provide an interesting perspective for the future)," said one, while another commented that, "I love that we're doing something like this—my friends are taking these boring classes and we're building models."

These questionnaires, as self-assessments, are useful since they are the strongest avenue in which students can register their engagement to us about the course, and suggestions for improvement. As such they are important teaching tools. However, they cannot be directly translated into the degree to which students actually learned things. Students learn more if more is demanded of them (Arum and Roksa 2011) and a less than hearty reception to the ABM classroom exercises should not be considered a sign of failure—on the contrary, it is expected from students who may be exposed to computational modeling for the first time, and then led through construction and defense of scenario building in the space of two to three weeks. The use of the NetLogo model was the most intellectually demanding and synthetic approach used in the course. Students needed to clearly understand the journal paper that described population-environment interactions in the Galápagos Islands, stakeholders that were represented, model data and relationships, and the user-interface that allowed student interactions with the model. Therefore, this activity required theoretical and applied skills in geography, spatial simulation, and the ability to synthesize information and to postulate reasonable scenarios of change in the Galápagos Islands.

Although the use of a model is challenging at any academic level, the papers that were written by the 2010 and 2011 classes showed a capability to articulate alternate futures of the Galápagos Islands and an understanding that extended beyond the course materials to include new ideas about the conflicts between resource conservation and economic development in protected areas and island ecosystems, including being able to link, and test, specific causal chains of potentiality with the aid of the agent-based model. The instructors interpreted these essays as showing outcomes consistent with cognitive activities commonly associated with critical thinking such as the ability to make correct inferences, and interpret and deduce conclusions given the data or evidence available (Pascarella and Terenzini 1991).

Discussion and Conclusions

The use of complex systems philosophies and approaches has been embraced in both graduate-level and undergraduate-level courses at UNC that focus on issues of resource conservation and economic development in the Galápagos Islands. Desired experiential outcomes were to encourage students to consider diverse scenarios of resource conservation and economic development and the tradeoffs inherent in the Galápagos by integrating human decision-making and ecological processes; and stimulate critical thinking through exposure to multidisciplinary and complex systems approaches within the classroom.

Among the topics that were addressed in the course were (1) differences that context and circumstances play in shaping perspectives; (2) changing student perspectives on key assertions about resource conservation and economic development in the Galápagos throughout the course; (3) shared relevance of local versus global perspectives in developing a unified vision of the archipelago that acknowledges local residents' needs without degrading the islands' unique ecological characteristics; and (4) enriching value of collaborative learning that draws insights, perspectives, and criticisms from beyond the UNC classroom.

Suggestions going forward concern mixed classroom teaching techniques and collaboration across countries, and in developing world settings. First, the use of alternate approaches to learning complemented the traditional learning experience, as student papers showed a real depth of understanding of dynamic systems supported by the synthesis of a diverse range of materials. In addition, students were exposed, some for the first time, to modeling

exercises. The authors believe that students learn more if more is demanded of them, in agreement with other recent findings (Arum and Roksa 2011), and therefore even such introductory exposure may signal a pathway toward learning in various dimensions that can help to build critical thinking skills in college students and society more generally.

The real-world setting and faculty field knowledge of the Galápagos Islands, and the associated social and ecological topics covered in the course, were clear advantages for students, signaled by their high ranking of both lectures and their opportunities to have face-to-face discussions with Galápagos residents and scientists (Table 2). Undergraduate education is increasingly looking to interdisciplinary, hands-on approaches to learning to better prepare students for entry into research-oriented and critical-thinking professions. Combined with basic education on the evolutionary biology, climate change, human impacts, and historical importance of the Galápagos Islands as a world-renowned island ecosystem, students were given a more rounded picture of the complexities among the social, terrestrial, and marine subsystems in the Galápagos archipelago, and in other islands, more broadly.

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Notes

1. More details on Netlogo, and many educational models, can be found at *http://ccl.northwestern.edu/NetLogo/*. This program operates within a Windows, Macintosh, or UNIX environment.
2. Living Galápagos (*http://www.livinggalapagos.org/*) is a multimedia project developed by undergraduates in the UNC School of Journalism and Mass Communications, based on field experiences, interviews, and videos collected in Galápagos during the summer of 2009.
3. Interviews were generally conducted in Spanish, and as Spanish language proficiency is not a requirement for the UNC course, videos were edited, translated, and dubbed into English.
4. Voicethread (*http://voicethread.unc.edu*) is a collaborative, multimedia online tool that allows members to share videos, audio, comments, and blog entries. No specialized software installation is required, making it an ideal environment for distance and international learning.
5. This experiment was made possible by a collaborative partnership begun in 2008, and referred to as the Galápagos Initiative, between USFQ, the leading private university in Ecuador and a top institution in Latin America, and UNC to advance a broad research, education, and community outreach agenda in the Galápagos. UNC and USFQ are committed to addressing the social and ecological dimensions of the Galápagos Islands by involving a diverse group of scholars and local and international perspectives. International education is fully represented in this initiative, as North meets South around the contentious issues of resource conservation and economic development in a World Heritage Site. Study abroad programs for summer and semester courses in the Galápagos were launched along with the course reported in this article.
6. A specialized NetLogo-ILLUM tutorial was also created for the class that specifically explained how the ILLUM model for Isabela can be exercised within the NetLogo environment.

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