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Unlocking the Educational Value of Large-Scale, Coastal-Ecosystem Restoration Projects: Development of Student-Centered, Multidisciplinary Learning Modules

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ABSTRACT

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Recent decades have witnessed the development and implementation of several regional-scale, coastal-restoration planning projects that deal with human–natural coupled ecosystems. With their rich contexts, societal importance and preavailable data and modeling resources, these projects offer unique, multidisciplinary learning opportunities that are yet to be tapped into, especially at the undergraduate level. The current study presents an effort to capitalize on these regional-scale projects and use their resources in undergraduate educational settings. The study describes the development of a set of Web-based learning modules that are situated in the Chenier Plain coastal ecosystem in Louisiana. Going through a comprehensive. coast-wide restoration-planning effort, coastal Louisiana is a unique ecosystem that captures the interactions between inland hydrology and coastal and wetland processes. Centered on the current crisis of coastal land loss in the region, the modules immerse students in a suite of active-learning experiences in which they prepare and analyze data, reproduce model simulations, interpret results, and balance the beneficial and detrimental impacts of several real-world coastal-restoration projects. The modules cover a wide array of topics, including system-scale analysis of water and salt budgets, use of numerical models in coastal hydrologic settings, linkages between hydrologic variability and vegetation regimes, and assessments of different restoration strategies. The article presents lessons learned, challenges, and students' perspectives from pilot classroom implementations to guide similar future efforts on using large-scale, coastal-ecosystem projects to enrich current educational practices in the field of coastal hydrology and other related topics.

ADDITIONAL INDEX WORDS: *Coastal hydrology, coastal Louisiana, data-driven learning, active-learning, Web-based education.*

INTRODUCTION

The field of hydrology has evolved to become a multidisciplinary science that includes different physical, chemical, and biological processes; spans vastly different settings (inland, estuarine, and coastal); and extend across a wide spectrum of spatial and temporal scales. The hydrologic research community has strived to formulate a research agenda for achieving real advances in the theory and practice of hydrologic sciences (Famiglietti et al., 2010; Gupta, 2001; Hooper and Foufoula-Georgiou, 2008). Key elements of this agenda include advances in observational settings, information systems, and modeling methods. Although such advances are rapidly emerging in research and industrial settings, parallel investments are needed in the educational field, especially at the undergraduate level. Problems facing current approaches to hydrology education stem from the narrow focus on single-system components and unit processes; thus, they lack the interconnectivity of various aquatic ecosystems that include streams, rivers, lakes, reservoirs, and wetlands. The spatiotemporal dynamics of hydroecological processes that span freshwater and coastal systems are rarely introduced in a formal way, producing graduates who are ill-prepared to address the complex problems facing today's society (*e.g.,* coastal subsidence, pollution, water management).

Recent decades have witnessed the development and implementation of several large-scale, ecosystem-restoration projects aimed at understanding the complexities of human–natural coupled systems and how they can be managed to

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balance economic benefits and preservation of wildlife habitats. Examples of such initiatives include the Chesapeake Bay Program (Chesapeake Bay Program, 2014), the Louisiana Coastal Master Plan (Coastal Protection & Restoration Authority of Louisiana, 2012), the Puget Sound Ecosystem Restoration Project (Gelfenbaum *et al.*, 2006), the CALFED Bay–Delta Program in California (Healey, Dettinger, and Norgaard, 2008), and the Florida Comprehensive Everglades Restoration Plan (U.S. Army Corps of Engineers and U.S. Department of the Interior, 2015). These projects and planning initiatives carry a wealth of resources and potential for enhancing education that have not been fully tapped, especially at the undergraduate level. For example, they provide (1) natural grounds for introducing multidisciplinary topics, (2) a wealth of data and modeling resources that can support instructors in developing engaging material, and (3) motivating contexts and linkages to societal problems that are not typically covered in today's classrooms. By leveraging these large-scale initiatives, educators can take advantage of the available data, models, case studies, and context richness to develop engaging student learning experiences.

The authors recognize these regional-scale restoration projects as unique, educationally rich ecosystems and present an example from Louisiana coastal ecosystems on how they can be used for undergraduate educational applications. Louisiana's coastal wetlands have been formed historically by the supply of freshwater and sediment deposition from local rivers. However, during the past century the natural buildup of land formations has become unstable because of anthropogenic alterations that have affected the hydrologic regime of the region. Such alterations include the construction of highways and levee systems, dredging of navigational channels, operation of gates and lock structures, and the impoundment and drainage of wetlands for agricultural, industrial, and urban use. The ultimate impact has been a decrease in land formation and an increase in land loss, which has threatened the economy, ecology, and culture of the region.

The coastal land-loss crisis currently threatening the Louisiana coast has prompted the development of a multibillion dollar, coordinated effort by local, state, and federal agencies to create a set of comprehensive restoration and protection plans to protect and restore the vanishing coastal wetlands. These and other parallel efforts by engineering firms, universities, and research institutions have created a wealth of analytical tools, data sets, and models, which are ideal resources for the development of learning materials and case studies (*e.g.,* Schoellhamer, 2009) that better represent the actual working environment of hydrologists, coastal engineers, and water resources managers. Building on these resources, the authors were able to focus their efforts on the educational aspects of the developments (*i.e.* how to tailor these resources for classroom applications), rather than on developing the content and tools from scratch. Six case studies, referred to as *modules*, were developed to cover a variety of hydrologic restoration concepts and proposed projects in the Chenier Plain basin of coastal Louisiana. Additionally, the modules take advantage of recent advances in the fields of geospatial visualization and Web-based technologies (Cunningham, 2005; Zia, 2004). This was performed by deploying the modules on an interactive, online Web platform (Habib, 2015). The development of these modules will enable an integrated introduction of several technical concepts connecting ecosystem processes that have been traditionally separated in most educational settings. Instilling in students a more holistic understanding of such processes is key to developing well-prepared graduates who are capable of dealing with the increasing complexity of coastal ecosystems.

METHODS

The methodology followed in developing the learning modules using coastal restoration efforts in Louisiana includes four main elements: the Louisiana Chenier Plain ecosystem in which the restoration projects are situated, the hydrologic and ecological data sets, the numerical model that provides pregenerated hydrologic simulations (stage and salinity concentrations) to be used by the students to perform the learning activities, and the active-learning design approach that was used to deliver the modules and the associated data sets and model outputs.

Ecosystem

The Chenier Plain ecosystem in SW Louisiana was the specific region under consideration for the development of the modules. It consists of approximately 6221 km^2 (2402 mi^2) of fresh, brackish, and salt marsh; open water; and Chenier habitats (Gammill *et al.*, 2002). This coastal basin is a rather unique system because it captures the transition from inland to coastal/wetland hydrology and actively serves several important ecological and economical functions. Because it is a multiuse ecosystem, the region faces challenges on how to reach a balanced and sustainable strategy among its various, often conflicting, functions (*e.g.,* oil and gas exploration, navigation, agriculture, fishing and hunting, and wildlife preservation). From an educational perspective, this ecosystem presents an excellent opportunity to enhance students' learning about fundamental hydrologic processes and the linkages between hydrologic sciences and engineering and other disciplines, including geomorphology, ecology, and economics.

The Chenier Plain is divided into two main subbasins: the Mermentau Basin and the Calcasieu-Sabine Basin. Historically, freshwater and nutrients from upstream basins were supplied to the region *via* seven major rivers (Figure 1). A major feature in this coastal basin is the 2092-km (1300-mi) Gulf Intracoastal Water Way (GIWW) (Figure 1). The GIWW is 3.7-m (12-ft) deep by 38-m (125-ft) wide channel extending along the northern edge of the region (Lehto, Marcantel, and Paul, 1993), linking deep-water ports, tributaries, rivers, and bayous. Although the navigational benefits of the GIWW are clear, it inadvertently complicates the regional hydrology by forming a major link between the different subbasins, which have historically existed as distinct systems. Additionally, the GIWW channelizes and diverts the freshwater sheet flow from upland catchments away to the Gulf of Mexico, thus severing freshwater flow to coastal marshes. It may occasionally act as an arterial route for saltwater intrusion during times of high tide or drought. To preserve the integrity of freshwater availability in the basin for rice agricultural purposes, five major water-control structures (locks and gates) have been

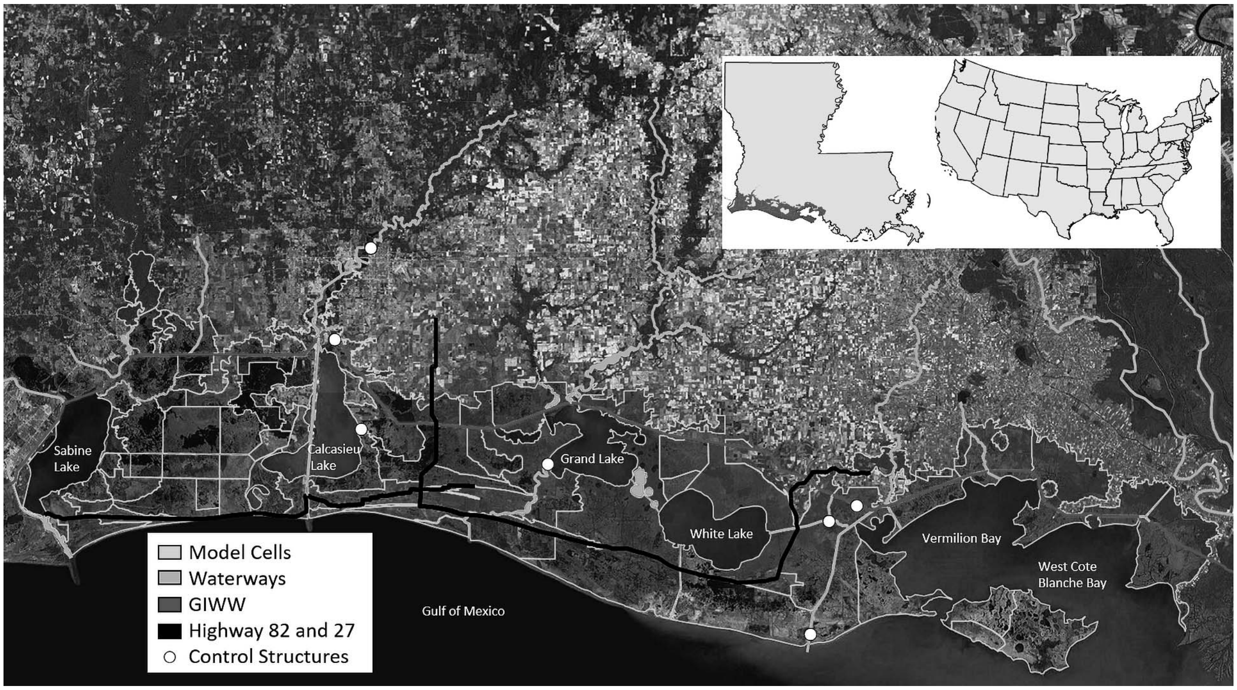

Figure 1. Location of the Chenier Plain Ecosystem in SW Louisiana showing upstream rivers, main waterways, including the Gulf Intra Coastal Waterway (GIWW), main lakes, and highways.

established along the perimeter of the area (Figure 1). These structures have altered the natural regimes of water and salinity variability, resulting in semi-impoundment of the entire basin. The basin hydrology has also been affected by the construction of major highways, which have created hydraulic barriers and prevented the natural gradient flow of water from N to S, eventually resulting in a large impoundment of freshwater in the basin. The lack of freshwater and nutrients from the north and the excavation of large navigation channels, such as the Calcasieu ship channel (CSC), have led to an increase in saltwater intrusion and vegetation loss in this coastal zone. In an effort to restore the hydrologic regime of the basin and support its various ecosystem services, numerous restoration projects have been proposed and are either under construction or planned for future implementation, including strategies such as freshwater introduction, terracing, marsh creation, and marsh management. The students' learning modules described in this study are based on some of those proposed projects and how they work to restore the ecosystem.

Data Sets

In studying the Chenier Plain ecosystem, the learning modules rely on, and take advantage of, the wealth of hydrologic and ecological data sets that have been developed during the years as part of past and ongoing restoration efforts in the region. These include data sets collected and archived by both federal and state agencies, such as the U.S. Army Corps of Engineers (USACE), the National Oceanic and Atmospheric Administration (NOAA), U.S. Geological Survey (USGS), the Louisiana Department of Natural Resources (LDNR), and the Louisiana Coastal Protection and Restoration Authority (CPRA). Data sets were also acquired from major wetland-monitoring and restoration programs, such as the Coastal Wetlands Planning, Protection and Restoration Act and the Louisiana's Coastwide Reference Monitoring System (CRMS; (Steyer *et al.*, 2003)). Most of these data sets are accessible through online data portals and provide many opportunities for developing data-driven learning experiences situated in an ecosystem-restoration perspective. A summary of these data sets and their online sources, if applicable, are listed in Table 1.

Mass–Balance Model Compartment Model

In addition to these publicly available data sources, the learning modules developed in this study also use modeling resources developed as part of Louisiana's 2012 Coastal Master Plan (CPRA, 2012; Peyronnin *et al.*, 2013). These come from a spatially distributed, mass–balance model that represents the hydrology of the Chenier Plain and simulates flux of both freshwater and saltwater within the region. Using simulation outputs from this model, students analyze the hydrologic regime (water level and salinity concentration) of the Chenier Plain under existing conditions and those of proposed restoration projects. The model represents the entire Chenier Plain with three types of interconnected compartment cells: channel, open water, and marsh. Each cell is represented by two main physical characteristics: surface area and ground-surface elevation or bed elevation for land and water cells, respectively. If a hydraulic connection exists between a pair of cells, these two cells are connected *via* a link. Each link has three physical dimensions: width, depth, and length. There are a total of 162

Table 1. *Sources of hydrologic and ecological data sets used in the learning modules.*

Variable	Source	Web Link
Water level	USACE	http://www.mvn.usace.army.mil/Missions/Engineering/Stage-and-Hydrologic-Data/
	CRMS	https://www.lacoast.gov/crms_viewer2/default.aspx#
Rainfall	USACE	http://www.mvn.usace.army.mil/Missions/Engineering/Stage-and-Hydrologic-Data/
	NCDC	https://www.ncdc.noaa.gov/
Evapotranspiration	IWMI	http://www.iwmi.cgiar.org/WAtlas/Default.aspx
Vegetation	CRMS	https://www.lacoast.gov/crms_viewer2/default.aspx#
Streamflow	USGS	https://maps.waterdata.usgs.gov/mapper/index.html
Salinity	LDNR	http://sonris.com/dataaccess.asp
	USGS	https://maps.waterdata.usgs.gov/mapper/index.html
	CRMS	https://www.lacoast.gov/crms_viewer2/default.aspx#

Abbreviations: USACE = U.S. Army Corp of Engineers, CRMS = Coastwide Reference Monitoring System, NCDC = National Climatic Data Center, IWMI = International Water Management Institute, USGS = U.S. Geological Survey, LDNR = Louisiana Department of Natural Resources.

cells and 397 links in the model covering the entire domain of the Chenier Plain (Figure 1). Figure 2 shows an example of multicell connectivity and how the model represents the complexity of the natural system in which a single cell may be connected to multiple neighboring cells or be connected to a single neighboring cell *via* multiple links.

If the connection between any two cells is through a controlled structure (*e.g.,* a gate, a weir, or a lock), the flow of water will be calculated using the flow equation for such a structure.

If the connection between two cells is not regulated (*e.g.,* flow through an open channel, or *via* surface drainage or sheet flow), the flow exchange between those two cells is calculated using typical, open-channel equations (*e.g.,* Manning's equation).

In addition to the water and salt exchanges among model cells, fluxes also come from exterior sources, including upstream rivers, downstream gulf passes, and the atmosphere (precipitation and evapotranspiration). The contribution of the upstream basins is implemented as boundary conditions *via* stream-flow records obtained from USGS stations for seven major rivers flowing into the region. Similarly, on the southern border of the model, a time series of offshore water levels from NOAA gulf stations are imposed as boundary conditions. The

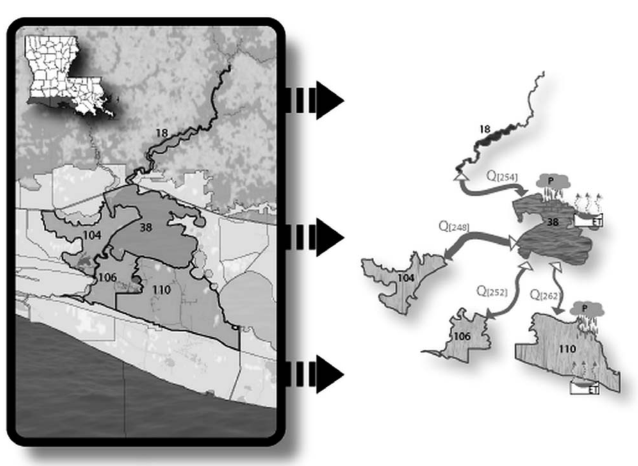

Figure 2. Conceptual cell and link configuration used in the hydrology model to represent the Chenier Plain ecosystem in coastal Louisiana.

model uses a daily time series of precipitation and evapotranspiration that were acquired from online archives of the National Climatic Data Center (NCDC) and the International Water Management Institute's (IWMI) World Water and Climate Atlas. The evapotranspiration (ET) rates from this atlas are based on the Penman-Monteith estimation method. The model applies an ET reduction factor in marsh cells to account for the effects of plant coverage.

Applying a mass–balance approach, the water level in each cell at the prediction time-step ($y[t_{k+1}]$) is calculated using a recursive formula with a time step (Δt):

$$y(t_{k+1}) = y(t_k) + \left\{ \left[\frac{\sum Q_{in}(t_k) - \sum Q_{out}(t_k)}{A} \right] + P(t_k) - ET \right\} \Delta t \quad (1)$$

where, A represents the surface area of the cell, $y(t_k)$ represents the water level at the previous time step, $Q_{in}(t_k)$ and $Q_{out}(t_k)$ represent inflow and outflow exchanges, respectively, with neighboring cells, and $P(t_k)$ and $ET(t_k)$ represent precipitation and evapotranspiration fluxes, respectively.

Similarly, the salt concentration in each cell can be expressed using the following equation:

$$C(t_{k+1}) = C(t_k) - \frac{C(t_k)}{V(t_k)}[V(t_{k+1}) - V(t_k)] + \frac{\Delta t}{V(t_k)}\left[\sum Q_{salt,in}(t_k) - \sum Q_{salt,out}(t_k)\right] \quad (2)$$

where, C represents salt concentration, and $Q_{salt,in}$ and $Q_{salt,out}$ represent the inflow and outflow of salt fluxes, respectively. These salt fluxes are estimated as the product of water fluxes between any two connected cells, multiplied, and the salt concentration of the contributing cell. The middle term in this equation accounts for the dilution or concentration from changes in water volume of the cell.

This cell and link configuration (Figure 2) provides a continuous coverage of the Chenier Plain, allowing for modeling of protection and restoration projects and the evaluation of the long-term effects of these projects on the ecohydrology of the region. To save model running time, which can be inhibitive to student work, model inputs and outputs have been prepared and are stored in online databases at the same site from which students access the modules. Through a geospatial online system, students can selectively download data required for analysis without needing to run the model directly. Once downloaded, students are able to apply concepts and equations of the original model in a more user-friendly and familiar environment, such as Microsoft Excel. Spreadsheet software, such as Excel, provides a more transparent environment for numerical simulations than the typical "black-box" models and has a rather moderate learning curve compared with command-line interfaces. By simulating these calculations on a smaller scale, students confirm the model's performance and develop a holistic understanding of these basic hydrologic processes and how they can be applied to solve practical, real-world engineering problems in a natural ecosystem.

Active-Learning Design Approach

The design of the coastal-restoration learning modules was informed by educational research on the effectiveness of student-centered, active-learning pedagogies. Recent data from the National Survey of Student Engagement (2015) suggests that course work that emphasizes engagement in higher-order learning and the use of effective teaching strategies is more likely to lead to student motivation and success. The design adopts the following key, high-impact strategies: (1) applying knowledge to practical problems and case studies (Bransford, 2000); (2) use of modern technology, visualization, and Web-based techniques (Zia, 2004); (3) connecting learning to real-world issues and rich contexts (Hoag, Lillie, and Hoppe, 2005; Lundebrerg, Levin, and Harrington, 1999); (4) user-support mechanisms to guide learners through the procedures while addressing a problem (Kolodner, Owensby, and Guzdial, 2004); and (5) developing conclusions based on one's own analysis. These strategies fall under the broad category of pedagogical strategies called *active learning* (Prince, 2004), in which students are actively engaged in discussing, analyzing, and collaborating. In particular, the modules were designed using technology-supported, case-based instruction with data, visualization, and simulations.

RESULTS

The results of this study are composed of two main elements: (1) a publicly accessible, Web-based platform that houses and serves the learning modules; and (2) a set of six modules that are based on actual case studies with multidisciplinary themes derived from recent coastal-restoration efforts in Louisiana.

Web-Based Platform

The study developed a Web-based platform in which the modules can be accessed by students and instructors (Habib, 2012). The platform primarily has three main attributes: (1) easy access to interactive tools to visualize real-world data in authentic contexts, (2) content and problem-solving tasks to engage students in systems and computational thinking, and (3) embedded user support (*e.g.,* screen casts, video demonstrations, textual scaffolds, and formative quizzes) to check student comprehension and provide just-in-time assistance. To further enrich students' learning experiences, the Web interface integrates the content and interactive display of data and model outputs as the students explore the domain of each learning module. Figure 3 shows how the interface integrates the (1) table of contents and learning tasks; (2) lessons that display full content (see Figure 5 for sample content); (3) map displaying the model domain, relevant geospatial data, and the spatiotemporal model simulations; (4) tool to toggle the base map; and (5) layers of geospatial maps and data sets that can be toggled. Interactive access to model output is supported as the user clicks on specific cells on the map (Figure 4). When the cell is clicked, the interface determines the surrounding cells, thereby displaying associated data in an intuitive format to support student learning.

As students advance through the modules, they can check their understanding through small, interactive quizzes, which refer students to sections for further study (see Figure 5, item 1). Each main section is followed by a set of quantitative learning activities that require students to perform data- and modeling-driven analysis for the different modules (presented in the next section). The activities are designed to be feasible for students from different backgrounds (*e.g.,* Civil Engineering, Geosciences), and the modeling and data-analysis tasks are mostly based on mass–balance concepts and can be completed using standard spreadsheet operations. To further support students' learning and their ability to complete the assigned tasks, several video tutorials and templates are provided (Figure 5, item 2) as part of the modules.

To keep students aware of the overriding context and the problem, each module is introduced with a problem statement that provides valuable context for the case study (*e.g.,* deteriorating wetlands in Louisiana's Chenier Plain). A concise list of key topics and expected learning outcomes are also included to support independent learning by the students and to ensure their awareness of the knowledge and skills they are supposed to achieve as they complete the modules. To support instructors in implementing the modules, information on target audience, tools needed, suggested grading and rubrics, expected completion time, and solution keys are also provided for each module.

Student Learning Modules

A total of six Web-based modules were developed using restoration problems and projects from the Chenier Plain and the Louisiana Coastal Master Plan. The first two modules precede the rest by laying the foundational groundwork; the first module introduces the complex coastal ecosystem of the Louisiana Chenier Plain, whereas the second module describes the mass–balance model applied to the region for assessing potential effects of restoration efforts. The third module focuses on conducting a regional water budget of the ecosystem to reinforce a student's understanding of factors contributing to the fragile hydrologic regime of the area. The fourth and fifth modules take advantage of two proposed restoration projects in the area: CSC Salinity Control project and Vermilion Bay Oyster Reef Restoration project. In each of these modules, students numerically simulate the physical changes of the project and then observe the relative effects on the environment, *e.g.,* water level, salinity level, habitat suitability index, and tidal prisms. The last module concentrates on connecting the hydrologic regime to vegetation growth in the region. In doing this, students make the connection between water availability, salinity, and marsh health and productivity.

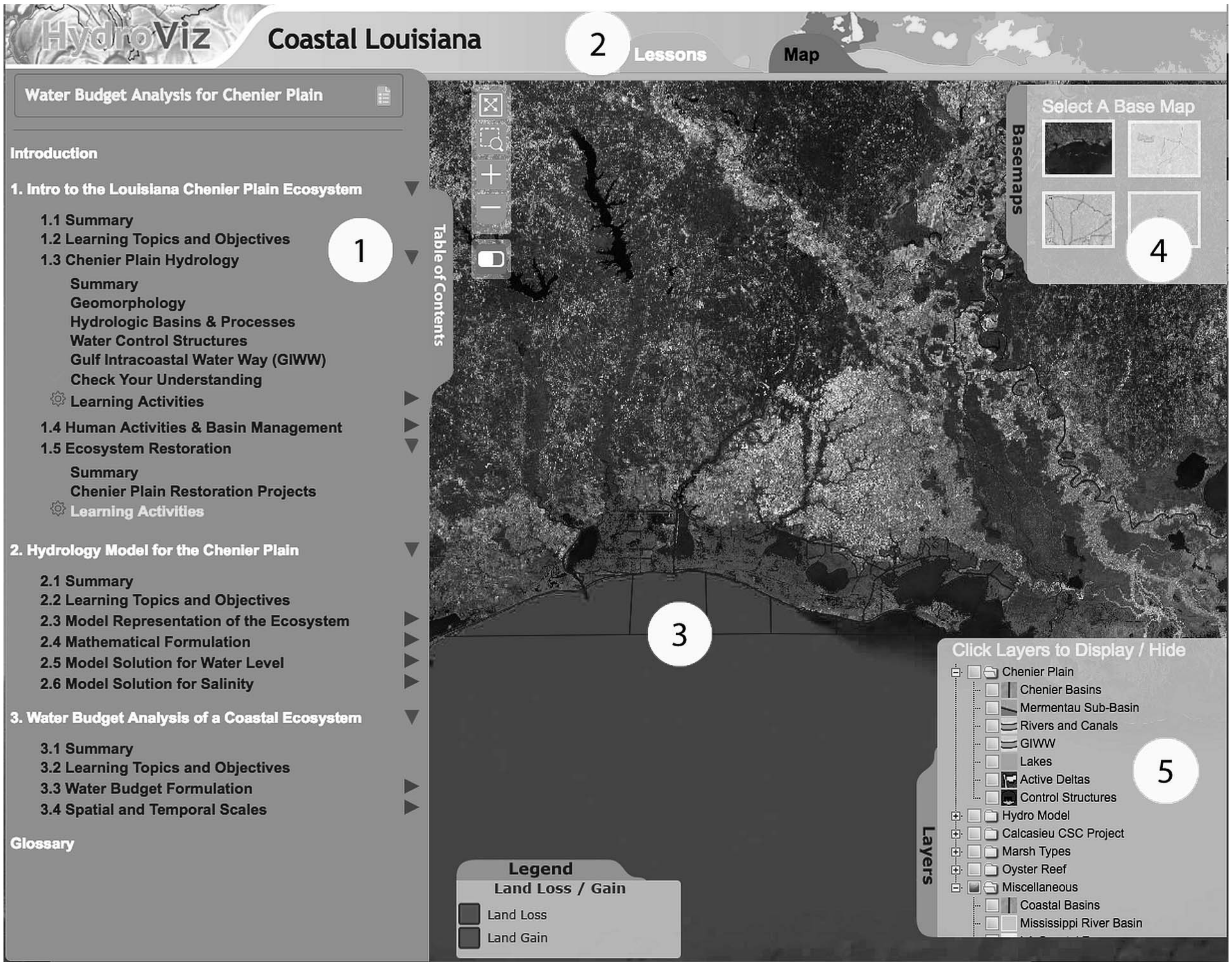

Figure 3. Interface of the Web-based modules hosted on the HydroViz platform (Habib, 2012); see article for description of items (1 to 5).

Module 1: Introduction to the Coastal Ecosystem

The first module provides an overall introduction to the Chenier Plain and acts as a precursor to the later modules. This objective of the module is to familiarize students with the natural ecosystem, focusing on its large-scale, physical features (*e.g.,* basin delineation, major rivers, marsh types) and the anthropogenic alterations that occurred during the past few decades (*e.g.,* dredging of channels, construction of major control structures, restoration efforts) and the effects those alterations have on system hydrology. Through a series of preliminary data-analysis and literature-research activities (Table 2), students develop a direct comprehension of how the natural processes, combined with those resulting from the built environment, have led to a persistent deterioration of the ecosystem and thus the need for ecosystem-scale restoration efforts. Such activities include examining the relationship between water level and rainfall variability (Figure 6), the effect of lock operations on the water level and salinity in upstream basins, and the implications of drought, excessive flooding, and salinity concentration on agriculture.

Module 2: Hydrology Model for the Chenier Plain

In this module (Table 3), students are introduced to the modeling system that was developed for as part of the 2012 Coastal Master Plan to assess and prioritize proposed restoration and protection projects. Students are first presented with detailed information as to how the model is setup to represent the natural environment using a control-volume approach. Details are given on the determination of the parameters of model cells, links among cells, model boundary conditions, and control-structure operations. The mathematical formulation and numerical solution of the model are then introduced in some detail, and students are asked to replicate small-scale results of the model using the previously derived mass–balance equations for both water level and salinity concentration. The HydroViz Web site houses the model results that were produced by the model. In a module activity, students are asked to reproduce the model calculations using spreadsheet software (Excel) and compare their own calculations to those produced by the model. Because of the large size of the model domain and the many cells involved, students perform the calculations over a

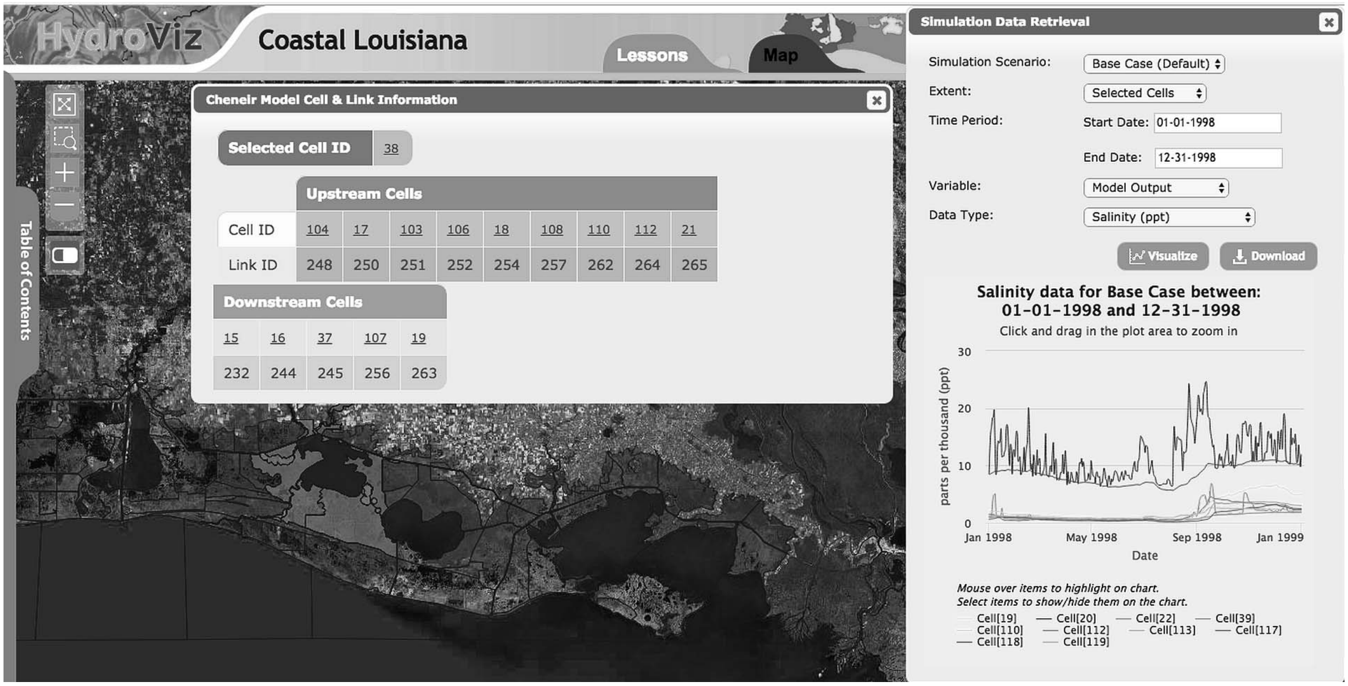

Figure 4. Web interface that houses the modules, illustrating interactive selection and display of model inputs/outputs.

subregion of the model domain that is composed of a single basin (cell) and the other basins (cells) that are connected to it. Students calculate water and salt fluxes across the different links and use them to predict changes in daily water level and salinity concentrations. By completing this module, students acquire a experiential knowledge of how

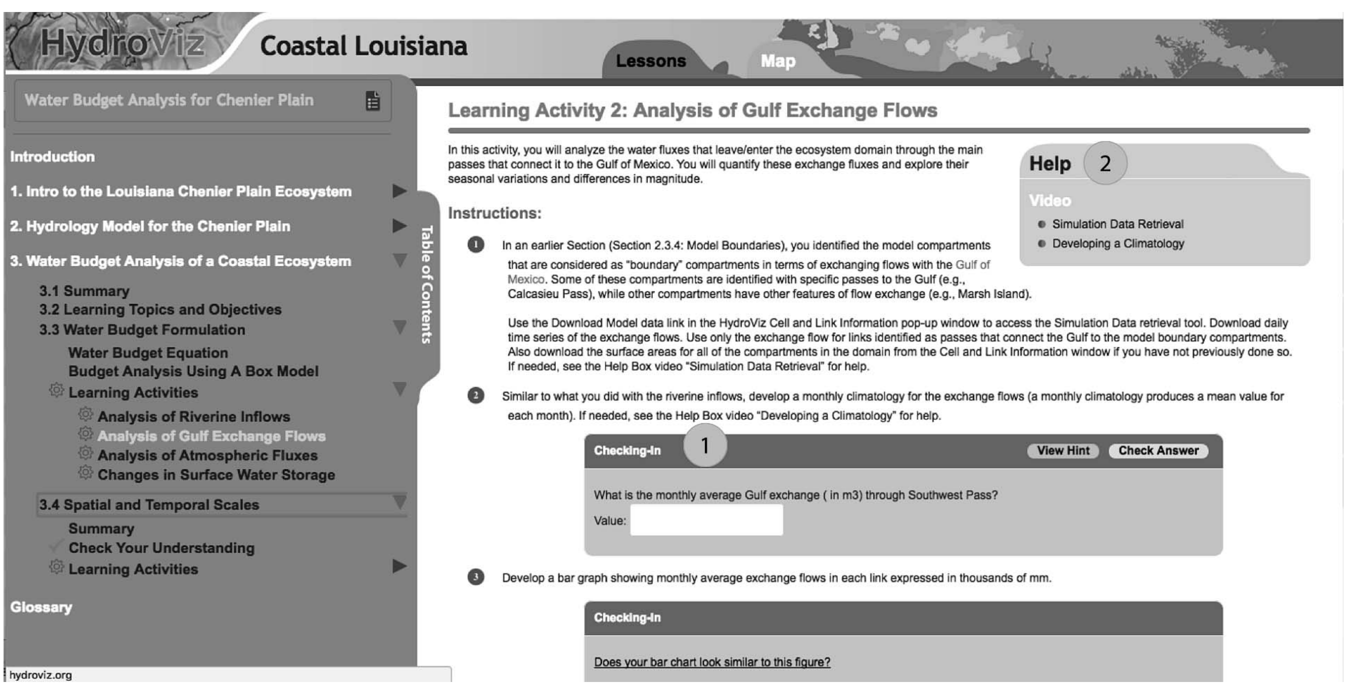

Figure 5. Example of the Lessons tab displaying content for each module and student's helpful resources; see article for description of the numbered items (1 to 2).

Table 2. *Overview of learning module 1: introduction to the ecosystem.*

Section	Subjects	Learning Activities
Ecosystem features	Hydrologic processes Water control structures	Analysis of water level and rainfall variability
Human activities and ecosystem management	Human-induced hydrologic alterations Conflicting management needs	Analysis of salinity variability and implications for agricultural practices
Ecosystem restoration	Chenier Plain restoration projects	Review of restoration strategies
Targeted student learning outcomes: Describe major physical and hydrologic features of the ecosystem Analyze variability in ecosystem hydrology and major fluxes Describe role of control structures in coastal ecosystems and their impact on hydrologic variability Describe effect of human developments on ecosystem hydrology Develop an understanding of competing demands imposed on the ecosystem by different stakeholders Understand the purpose of coastal-restoration activities Become familiar with online resources on coastal restoration and use them to demonstrate purpose of various restoration techniques		

spatially distributed box models can be used to simulate the hydrology of a large-scale coastal ecosystem and changes in its water level and salinity regimes in response to freshwater and saltwater fluxes.

Module 3: Water Budget Analysis for a Coastal Ecosystem

Water budget analysis of large, coastal basins provides a basis for understanding the hydrologic and ecologic processes of the ecosystem, its ecological functions and services, and how to predict effects of natural and human hydrologic alterations. In this module (Table 4), students use the output of the spatially distributed mass–balance model (developed earlier in Module 2) to perform a water budget analysis for the entire Chenier Plain ecosystem. They begin by examining the major water-budget components, including riverine inflows from upstream catchments, tidal exchanges with the Gulf of Mexico, and atmospheric fluxes in the form of precipitation and ET. Students develop a monthly climatology (*i.e*. 20-y average for each month) for each of these hydrologic components and examine their relative magnitudes, seasonal variability, and intercorrelations (Figure 7). As part of these activities, students are exposed to how a water-budget analysis can be performed at different scales spatially (single basin, region) and temporally (seasonal, annual). Students also develop an understanding of the natural variability in the water budget both at interannual and intraannual scales. Students are then asked to connect such variability to the overall climatology of the region and its historical drought and flood years, using indices such as the Palmer drought severity index and its hydrologic version know as Palmer hydrologic drought index. The module asks students to reflect on their analysis and synthesize their results by answering questions on the dominant water-budget components, how the water budget changes seasonally, possible causes of the seasonal variations in the water storage term, the role of riverine inflows that bring freshwater into the ecosystem in relationship to water fluxes that exit the system through Gulf passes. Students are also asked to discuss the implications of their observations on the loss of freshwater from the ecosystem and the potential for saltwater intrusion from the Gulf.

Module 4: Case Study—The CSC Salinity Control Project

With the excavation of navigation canals and the widening and deepening of existing waterways, saltwater intrusion from the Gulf of Mexico has contributed to coastal wetland loss in Louisiana. This situation is best illustrated in the SW region of the Chenier Plain, where a major navigation waterway (CSC) passes through one of the main lakes (second lake from the left in Figure 1). This module guides the students through a set of activities (Table 5) to analyze the existing hydrologic conditions in the CSC region and to investigate different alternatives for salinity-control measures. The overriding theme is how to

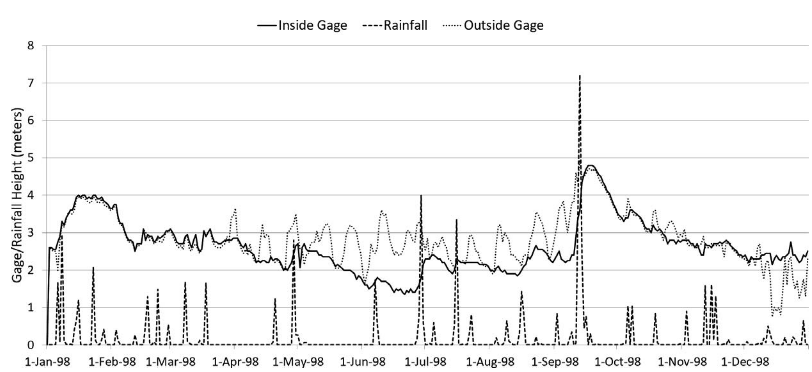

Figure 6. Example of students' analysis of the basin hydrologic regime: students examine the relationship between rainfall and water level variability inside and outside the basin and relate these processes to the operation of control structures.

Table 3. *Overview of learning module 2: hydrology simulation model for the Chenier Plain.*

Section	Subjects	Learning Activities
Model representation of the ecosystem	Model cells and links	
	Representation of hydraulic control structures	
	Model boundary conditions	
Mathematical formulation	Mass–balance equation	
	Single- and multibox model	
Model solution: water level	Discretization of water balance equation	Modeling daily changes in water level
	Model simplifications and assumptions	
Model solution: salinity	Discretization of salt-balance equation	Modeling daily changes in salt concentration
	Salt flux calculations	

Targeted student learning outcomes:
- Describe how spatially distributed box models are used to simulate water and salt storages and fluxes in a large coastal ecosystem.
- Describe how the simulation model represents physical features of the Chenier Plain as an example of a coastal ecosystem.
- List types of model inputs, outputs, and boundary conditions
- Describe the mathematical formulation of spatially distributed box models and their numerical solutions

regulate saltwater intrusion and how to allow the continued functioning of the ship channel and the Port of Lake Charles. The module starts with an overview analysis of the basin and its hydrologic regime and then moves to a quantitative evaluation of four different alternatives that are proposed as salinity-control measures. The alternatives represent different combinations of hydraulic-control structures, such as locks, gates, sills, and impermeable control structures to control the quantity of saltwater entering the CSC and the surrounding marsh areas. Students use the same mass–balance box model described earlier to simulate and analyze the potential effect of the different project alternatives on key hydrologic attributes, such as water levels and salinity concentrations. They also quantify the effect on integrative metrics, such as the tidal prism and flux exchanges with the Calcasieu Lake and the surrounding wetland areas. The module closes with a set of investigative questions that require the students to reflect on their results and assess the different proposed alternatives considering factors such as constructability, long-term operation, cost, and implications for local residents and private land owners.

Module 5: Case Study—Vermilion Bay Oyster Reef Restoration Project

Bioengineered oyster reefs are used as a viable restoration measure in many coastal ecosystems in the United States and other world regions. They provide structural protection of shorelines because they act as barriers against storm surges and provide ecosystem services in the form of habitat for oysters. As part of the 2012 Louisiana Coastal Master Plan, an oyster reef restoration project was proposed for Vermilion Bay in the Chenier Plain coastal ecosystem (Figure 8). In this module, students perform a modeling-based analysis to investigate how the oyster reef will affect the hydrologic regime in the proposed site, assess whether it can successfully meet its restoration goal, and examine potentially negative effects on habitat suitability for other key harvested species supported by the ecosystem. Using the same model described above, students can analyze changes in water level, salinity, and exchange flows as a result of building the oyster reef in the proposed location. The module guides the students through a series of activities (Table 6) that start with modifying the existing model to simulate the presence of the reef. Preproject and postproject simulations are then performed for a representative 2-y period (low *vs*. high sea levels), which also include a large tropical storm that hit the region in 1998. Students analyze the effectiveness of the reef in reducing wave impacts by examining the reduction in the amplitude of water-level variability within the bay and the overall reduction in exchange flows with the Gulf, especially during extreme weather events. Students are also asked to examine whether the reef results in an increase in exchange flows in other areas, which can possibly lead to shoreline erosion. Closing the module, students reflect on the results and assess whether the proposed reef accomplishes its intended goal, review potential negative effects, examine whether the negative effects outweigh the anticipated benefits, and propose measures by which negative effects can be mitigated.

Table 4. *Overview of learning module 3: water budget analysis for a coastal ecosystem.*

Section	Subjects	Learning Activities
Water-budget formulation	Water-budget equation	Analysis of riverine inflows
	Budget analysis using a mass-balance spatially distributed box model	Analysis of Gulf exchange flows
		Analysis of atmospheric fluxes
		Estimation of changes in surface-water storage
Budget scales	Spatial and temporal scales	Inter- and Intra-annual variability

Targeted student learning outcomes:
- Define main components of a water budget in a coastal ecosystem
- Formulate and perform a mass–balance water-budget analysis for a coastal ecosystem
- Analyze dominant hydrologic processes for flow exchanges and water-level variability in a coastal ecosystem
- Become familiar with Web sites that house long-term coastal hydrology data sets
- Analyze inter- and intra-annual variability in main hydrologic processes
- Discuss the implications of variability in water budget from an ecosystem service perspective

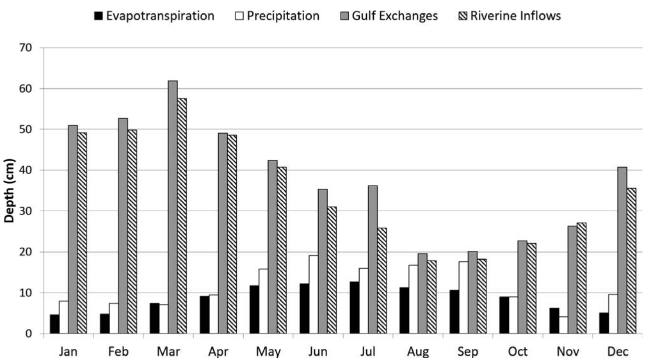

Figure 7. Example of students' analysis of seasonal variability in the major components of the water budget in the Chenier Plain ecosystem (units are expressed as volume normalized by the surface area of the study domain).

Module 6: Analysis of Vegetation Changes

The ultimate goal of coastal-restoration projects is to promote the creation and protection of a variety of habitats within the ecosystem. Successful habitat creation relies on the ability to predict which plant communities will result from proposed management and restoration actions. Habitat restoration, creation, and protection are achieved by manipulating hydrologic conditions, mainly flooding and salinity regimes, to promote desired plant communities. However, the relationships that govern the response of wetland ecosystems to hydrologic manipulations are quite complex. This module (Table 7) builds a basic understanding of hydrology and vegetation interconnections and provides a quantitative analysis of how the hydrologic regime (*e.g.,* flooding frequency and salinity variability) affects changes in wetland types, vegetation, and plant species. The module includes interpretation of hydroecologic field observations from the CRMS statewide coastal-monitoring network, as well as modeling and analysis of hydrologic indices for assessment of marsh health and robustness of vegetation productivity given certain hydrologic conditions.

DISCUSSION

The modules were implemented and evaluated in two elective courses, with a focus on assessing their usability and the perceptions developed by the students after completing the different tasks. The evaluation also provides insights on lessons learned and challenges encountered that can guide similar future efforts.

Evaluation and Assessment

Evaluation of educational developments, such as those described in this study, is a critical component that can help assess the actual benefits from a student learning perspective. Although a full evaluation and assessment is beyond the scope of this article, this section presents insights from a pilot-scale implementation of the modules in two elective hydrology courses. The classes consisted of a mixture of 30 undergraduate and first-year graduate students. The classes included students from civil engineering, geosciences, and biology. Students had different technical backgrounds on coastal systems and some awareness of coastal-restoration problems in Louisiana. Students were asked to work individually but were also encouraged to collaborate through discussions and online forums that were set as part of the class. The modules were assigned as out-of-class assignments during which students were allotted 1–4 wk to complete each module, depending on the length and difficulty of the particular module. Upon completion of the modules, students presented and discussed their results in follow-up, in-class sessions with their peers and the instructor. Student submissions were graded using rubrics that were made available to students to inform them of both what should be submitted and to stress the relative importance of each section of the respective module. With the exception of the "Water Budget Analysis for a Coastal Ecosystem" module, students were able to successfully complete the different learning activities and provide adequate analysis and discussions of the results. The less-than-satisfactory performance on the basin-wide, water-budget module was attributed to the unusually large data sets and model outputs associated with this module, which can be best approached using some programming skills that undergraduate students typically lack.

In addition to grades, informal interviews were conducted at the conclusion of each course during which the modules were introduced. The purpose of these interviews was to gather qualitative assessment data on (1) students' perceptions of the usability of the modules, (2) design attributes that support student learning (*e.g.,* clarity of instructions, quality and quantity of user support), (3) gain insight into the effectiveness of using the modules as an instructional approach, and (4)

Table 5. *Overview of learning module 4: Calcasieu Ship Channel (CSC) salinity control project case study.*

Section	Subjects	Learning Activities
Introduction to the project	Project location Need for project	Analysis of site hydrology
Tidal exchange in an estuarine system	Tidal prism	Analysis of tidal exchange
Modeling and assessment of project alternatives	Project alternatives Model modifications Assessment of project alternative impacts	Effect on water level and salinity Effect on lake tidal exchange Comparative evaluation of different alternatives

Targeted student learning outcomes:

- Identify the overall objectives of a major restoration project, and place these objectives in context with reasonable and achievable goals of individual project alternatives
- Analyze the effect of hydraulic structures and other restoration measures on ecosystem performance, specifically the salinity dynamics
- Identify and analyze the hydrologic/ecologic factors that are directly and indirectly affected by the salinity-control restoration-project alternatives
- Discuss trade-offs in project selection, and be able to make recommendations on which project alternatives should be selected and why

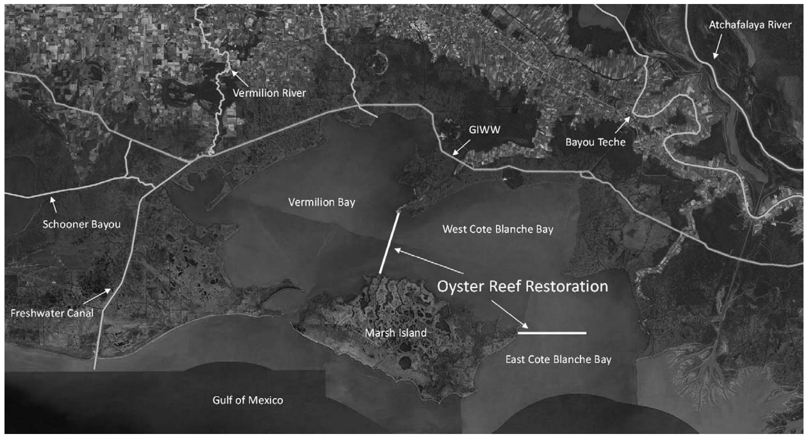

Figure 8. Location of the oyster reef restoration project used in one of the modules.

gauge students' interest in the field of coastal hydrology and ecosystem restoration. In the analysis of data on usability, students expressed an appreciation for the Web-based design of the modules and the availability of a geospatial navigation component from which they could access the specific sites of the restoration projects and interact with related data sets and model outputs, all in one environment. Students appreciated the map component of the Web site, which allowed them to visually understand the textual context of the modules, especially when references were made to the geographical layout of the model domain. Additionally, the overlays allowed self-navigation of the domain and enabled students to locate features necessary in the activities as well as items of personal interest (evidence of intrigue). Design elements that were most valued by the students were the user-support mechanisms embedded into the modules. The concept of the "checking in" and "checking your understanding" quizzes were very popular, and students recommended areas within the modules were quizzes could be further implemented to confirm students' answers and understanding and avoid error buildup, especially when the analysis required lengthy calculations and simulations. Additionally, students indicated that support mechanisms, such as videos, instructional images, and templates were highly useful and likewise requested the inclusion of more of these mechanisms in difficult areas of specific activities. Students even suggested including additional forms of support, such as warnings in sections where common mistakes are made.

The use of learning activities that stem from actual, large-scale restoration projects as an instructional approach was well received. The inclusion of the first two modules as predecessors of the other modules was deemed an excellent idea for they sufficiently introduced the ecosystem for individuals not familiar with the area and familiarized the students with the structure and concepts of the mass–balance model, which were used in the later modules. Students found the case-based learning format of the modules to be very effective. They mentioned that the hands-on approach was very appealing and was something not available in other classes. They felt learning from real-world cases studies that are of regional or national prominence stimulated their interest in the field. Students also cited how these data and modeling-rich learning environments helped them gain skills that would be useful in their future careers. The use of real-world problems and the case-based approach was helpful to ground their learning in a systematic fashion, starting from data collection and preprocessing, to modeling analysis and decision making. Specifically, students mentioned their new knowledge of advanced spreadsheet

Table 6. *Overview of learning module 5: Vermilion Bay Oyster Reef Restoration project case study.*

Section	Subjects	Learning Activities
Introduction to the oyster reef restoration project	Why oyster reefs project hydrologic and vegetation regimes	Delineation of project domain Water budget analysis
Modeling an oyster reef project l	Model modifications	Impact on water-level variability Impact on salinity
Trade-off assessment	Desirable *vs*. undesirable impacts Habitat suitability for wildlife species	Effect on shoreline protection Impact on Gulf exchange flows Impact on brown shrimp habitat

Targeted student learning outcomes:
- Describe the use of oyster reefs as a coastal restoration/protection strategy
- Describe use of hydrologic models to represent an oyster reef and simulate its hydrologic impacts
- Analyze water level and salinity patterns to assess the hydrologic impact of oyster reefs
- Analyze the role of oyster reefs during extreme events
- Evaluate habitat suitability indices under different hydrologic conditions with and without the oyster reef project
- Analyze positive and negative impacts of an oyster reef restoration project on the ecosystem hydrologic regime and its ecological services

Table 7. *Overview of learning module 6: analysis of vegetation changes from hydrologic regime alteration.*

Section	Subjects	Learning Activities
Hydrology regime and marsh classification	Marsh and vegetation types Interactions between hydrology and vegetation regimes	Introduction to the Coastwide Reference Monitoring System Marsh classification based on salinity and water-level variability
Vegetation productivity and hydrology	Hydrologic index	Assessment of hydrologic stress on vegetation
Modeling changes in submerged aquatic vegetation	Regression model for submerged aquatic vegetation	Estimating net changes in submerged aquatic vegetation

Targeted student learning outcomes:
- Describe different methods used to determine and classify marsh and vegetation types
- Analyze hydrologic regime (salinity and water level magnitudes and variability) and classify marsh type
- Assess marsh productivity using a hydrologic index
- Describe the hydrologic drivers of changes in marsh vegetation composition
- Estimate changes in vegetation composition using output of a hydrology simulation model

operations and the challenges associated with using large data sets as very beneficial skills for the future. No notable differences were observed in performance of students from different backgrounds. Although both undergraduate and graduate students appreciated, the learning experiences offered by the modules, their views differed on some issues related to the specificity of the learning tasks. Although undergraduate students expressed deep appreciation for the detailed, step-by-step instructions, several graduate students mentioned that the instructions were too specific in some areas; which prevented them from being able to approach the problem in their own way. They argued that although the very detailed instructions allowed everyone to get to the final answer, all answers were essentially "clones" of the same approach. In this way, they felt the instructions should be more open-ended, so as to not take away from the investigative component of the student-centered approach.

Limitations and Challenges

Although large-scale, multidiscipline restoration projects bring exciting and unique learning opportunities that the community should tap into, they also come with developmental and implementation challenges. The use of learning modules that are rich in content, large in scope, and heavy in use of data and models can be overwhelming to both students and professors. Students can potentially get overwhelmed by these types of assignments and might develop learning resistance that defeats the intended outcomes. In developing these resources, it is critical to strike the right balance between the level of detail and step-by-step, procedural instructions that allow successful task completion and the open-ended directions that promote hypothesis formulation and inquiry-based learning. Based on student feedback, user-support and feedback mechanisms were critical in facilitating their work; however, foreseeing where students might make mistakes or need assistance is a challenge. For this reason, developers must be careful to present material with the proper curricular expectations, ensure connections to basic concepts that the students are familiar with, and embed interactive tools to support students' progression through the lessons and activities. Inclusion of user supports, such as video tutorials, geospatial visualization tools, and formative feedback quizzes, can help to reduce the steep learning curves often associated with such approaches. When implementing these types of learning activities in a course, much thought should be given to time limitations. To ensure that students do not lose the overall purpose of the project at hand, modules should be able to be completed within a relatively short period; however, students need sufficient time to work through the activities, analyze and discuss results, and then potentially address mistakes made. If a module is being used to reinforce concepts taught in the classroom, then perhaps, it makes sense to introduce the module at the end of the semester; however, this may result in overlap with end of the semester exams and deadlines. This overlap tends to restrict students' time and may result in poor performance in module activities and thus reduced educational benefit.

Assessing the actual effect on student learning from these types of modules, especially in a quantitative manner, is another challenge. The fact that the interdisciplinary topics and data and the modeling concepts targeted by the modules are not typically covered in traditional curricula makes it difficult to objectively assess students' performance using well-established methodologies, such as the use of control groups. In addition, the complex nature of the activities, during which students are required to retrieve and preprocess data, use their judgment and intuition to make decisions, and present and discuss results, may lead them to different paths, thus making assessment and evaluation fairly challenging.

Finally, dissemination and adoption of the types of modules proposed in this study is yet another challenge. There is a need to develop a better understanding about how other instructors see the value of such approaches at the undergraduate level and how much resistance or receptiveness is expected from students and professors. Other factors relate to how students from other geographical regions appreciate the context of the learning content and tasks developed for an ecosystem or a basin outside of their regional proximity.

CONCLUSIONS

This article presented the development of a set of undergraduate learning modules that leverage data and modeling resources from large-scale, coastal-restoration projects and planning studies. A total of six modules expose students to interdisciplinary subjects and investigative tasks, such as regional-scale water budget analysis, inter- and intraannual variabilities in hydrologic processes, analysis of alternatives for managing salinity intrusion and navigational needs, hydro-ecological tradeoffs in designing coastal-restoration projects, and the effect of hydrologic changes from vegetation- and habitat-suitability perspectives. As students work on these modules, they are exposed to contemporary topics that deal with social and natural dimensions of ecosystems and, at the same time, gain valuable skills on how data and models are being used within the context of large-scale coastal-restoration projects. Building on the complexity and deep context of these projects, the learning modules immerse students in real-world ecosystems and guides them through a series of analyses using data and modeling techniques to determine the relative feasibility and effect of different coastal restoration measures. Students get context-rich experiences in using data and model outputs currently being used in real-world assessment of potential, multimillion-dollar projects in coastal ecosystems. In this way, students are introduced to the complexities of altering the hydrologic regime of fragile ecosystems, consider cross-discipline ramifications of such alterations (*e.g.,* vegetation, habitat suitability, navigation, industry), and develop an appreciation of data scarcity and model complexities and limitations in designing and testing the feasibility of proposed restoration projects. The modules developed in this study are built using case studies and actual restoration projects in coastal Louisiana. Other regional-scale coastal ecosystems in the United States can be used to provide similar student-centered learning opportunities.

It is highly recommended that instructors interested in taking advantage of resources available through large-scale ecosystem-restoration and planning endeavors approach and collaborate with state and federal agencies that are in charge of these systems, as well as with consulting firms who are engaged in the design and implementation phases. These entities provide unique perspectives to support the formulation of meaningful student problems, and they give access to the necessary data sets and model outputs. Establishing a working partnership between the educational and agency communities can significantly reduce development effort on the instructors and affords the institution the opportunity to have a significant effect on the undergraduate education and the respective field as a whole.

The modules were subject to a qualitative evaluation in two hydrology elective courses. The modules were assigned as independent, out-of-class projects. Students' performance in the different tasks, as well as the feedback received from postmodule interviews, provided valuable insights on their perceptions of the educational value of using large-scale restoration projects for educational activities. Overall, students indicated that the modules were an excellent change of pace from traditional classroom topics, and many of them appreciated the exposure to critical ecosystem restoration problems and the role engineers and scientists have within these multidiscipline systems. The evaluation provided valuable insight on limitations and challenges encountered in this study, including students and instructor's receptiveness, dissemination and adoption by audience from different regions, and quantitative evaluation of learning impacts. Future efforts that address these challenges may encourage the development of similar efforts that draw from the educational power of large-scale, regional, coastal-ecosystem projects to make a larger impact beyond individual institutions.

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