Student Perceptions of an Active Learning Module to Enhance Data and Modeling Skills in Undergraduate Water Resources Engineering Education

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Abstract

This article describes the design, development, and evaluation of an undergraduate learning module that builds students' skills on how data analysis and numerical modeling can be used to analyze and design water resources engineering projects. The module follows a project-based approach by using a hydrologic restoration project in a coastal basin in south Louisiana, USA. The module has two main phases, a feasibility analysis phase and a hydraulic design phase, and follows an active learning approach where students perform a set of quantitative learning activities that involve extensive data and modeling analyses. The module is designed using open resources, including online datasets, hydraulic simulation models and geographical information system software that are typically used by the engineering industry and research communities. Upon completing the module, students develop skills that involve model formulation, parameter calibration, sensitivity analysis, and the use of data and models to assess and design a hydrologic a proposed hydrologic engineering project. Guided by design-based research framework, the implementation and evaluation of the module focused primarily on assessing students' perceptions of the module usability and its design attributes, their perceived contribution of the module to their learning, and their overall receptiveness of the module and how it impacts their interest in the subject and future careers. Following an improvement-focused evaluation approach, design attributes that were found most critical to students included the use of user-support resources and self-checking mechanisms. These aspects were identified as key features that facilitate students' self-learning and independent completion of tasks, while still enriching their learning experiences when using data and modeling-rich applications. Evaluation data showed that the following attributes contributed the most to students' learning and potential value for future careers: application of modern engineering data analysis; use of real-world hydrologic datasets; and appreciation of uncertainties and challenges imposed by data scarcity. The evaluation results were used to formulate a set of guiding principles on how to design effective and conducive undergraduate learning experiences that adopt technology-enhanced and data and modeling-based strategies, on how to enhance users' experiences with free and open-source engineering analysis tools, and on how to strike a pedagogical balance between module complexity, student engagement, and flexibility to fit within existing curricula limitations.

Keywords: water resources engineering education; active-learning; numerical modeling; data analysis; project-based; improvement-focused evaluation; design-based research; open-source tools

1. Introduction

The use of numerical models and data analysis techniques has become an established practice in both industrial and research settings in the field of hydrology and water resources engineering [1]. However, the use of these tools in undergraduate water-related courses is largely lagging. The desire to introduce advanced data and modeling-based activities in undergraduate settings has been emphasized by several initiatives within the hydrologic community ([2,3]. The use of modeling tools within a project-based context can facilitate hypothesis and discovery-driven learning [4], and as such provides a more holistic understanding of advanced concepts [5]. Additionally, modeling tools and data resources that will be utilized in a future career can promote motivation and increase knowledge transfer to non-academic contexts (Merwade and Ruddell, 2010). Despite the recognized need for introducing data analysis and modeling skills, the development and implementation of learning resources faces several challenges in terms of: scalability and sustainability issues, lack of financial resources, accessibility to datasets and modeling tools, and effective strategies on how to integrate new resources into existing curricula. In many universities, hydrology and water resources engineering is taught in a single course that encompasses diverse areas of the subject, leaving little time for additional materials that focus on data analyses and modeling [6]. A more likely strategy for integrating these resources into existing undergraduate classrooms is through activities such as projects and case studies that rely on independent work by the students, with the instructors playing a supporting role [3]. While this strategy offers solutions for overcoming in-class time limitations, it presents challenges for the design of data modeling-based learning resources. The processes involved in model development and application (e.g., setup, calibration, data pre- and post-processing) can be overwhelming to students and the associated learning curve tends to be quite steep, especially when undergraduate students represent the main audience. Therefore, the design of new modeling-based learning resources should alleviate the need for direct instructor assistance. Such design can also support the scalability of modeling-based innovations in hydrology education. As suggested by Rogers' theory on diffusion of innovation [7] and by more recent studies in the field of engineering education [8], the design attributes of a certain innovation can play a major role in achieving a scalability solution and future adoption by the teaching community. Accessibility to software and datasets can also be a prohibitive factor in wide dissemination and adoption of the new resources. In this context, the use of free software, open-source tools, publicly-accessible data portals and web-based technologies can provide viable solutions for achieving a wide-scale use of the new resources. Over the recent years, the international educational community has strongly promoted a vision based on the principles of free, openly licensed educational resources (OER) ([9-10] as a viable approach for enhancing accessibility, sharing and democratization of educational resources.

The use for open resources within the field of hydrology and water resources engineering education has emerged as a community vision ([11] with an expressed need for increasing investments in providing open access to data and modeling tools. Building on these recent efforts, the overall goal of the current study is to investigate how data and modeling-based learning activities can be designed using an open-access, student-centered approach. We describe the development and evaluation of an active-learning module that adopts a project-based approach to introduce modeling and data analysis skills into undergraduate water resources engineering curriculum. Besides the well-established research on the effectiveness of project-based and active-learning pedagogies [12-13], the use of actual case studies provides a natural solution for introducing modeling concepts and skills. Using a project-based approach, students can be immersed in an active hydrological learning environment, where they are presented with an overall problem context (technical, environmental, and societal), and in the meantime, confronted with the limitations in the available data, analytical tools and simulation models. To ensure independent use and adaptation, the module is made available to the wider community through an open-access online platform, and relies on free resources, including hydrologic datasets, hydraulic simulation models and geographical information system software that are widely utilized by the engineering industry. The design of the module builds on the evidence-based research on how user-support mechanisms, scaffolding and corrective feedback can keep the learning activities interactive [14] and improve student learning [15]. Our study adopts a design-based research approach [16] and implements an iterative process of module development, evaluation, documentation, and reflection. The evaluation focuses primarily on assessing students' perceptions of the module usability and its design attributes, and the perceived contribution of the module to their learning. Another critical, but less appreciated factor that may impact successful introduction of active-learning materials is student resistance to technology-enhanced pedagogy [17-19]. Therefore, we also examine students' receptiveness to the module and its overall approach, and how it impacts their interests in the field of water resources engineering. The study formulates a set of design principles to inform parallel and future activities that aim at the development and use of open-access modeling and data-based learning resources in undergraduate settings.

2. Methods

The module is comprised of two phases and can be accessed through the following two links: (Phase 1: http://hydroviz.org/Lessons/Index/LA/PecanIslandFeasibility and Phase 2: http://hydroviz.org/Lessons/Index/LA/PecanIslandChannelDesign), both located on the HydroViz learning platform (www.hydroviz.org). The module design is based on using the following main pedagogical and technical criteria: (a) using a real-world case study with an actual hydrologic restoration project; (b) building the educational content around a set of student-centered, data and modeling-based learning activities; (c) providing extensive student-support and scaffolding mechanisms; and (d) using open-source and publicly-accessible resources, including online datasets and simulation models that are typically used by the engineering industry and research communities. Such design provides students with authentic learning experiences, allows them early access to real-world complex engineering problems, empowers them with self-learning tools, and answers to the need for promoting open access, sharing, collaboration and democratization of educational resources. The following sections provide a brief description of the overall approach and specific pedagogical and technological methodologies that were used to design and develop the module.

2.1. Hydrologic Restoration Project

The current study was developed based on a real-world coastal restoration project located in Pecan Island, a small community in Vermillion Parish, Louisiana (Figure.1). Pecan Island is surrounded by brackish marsh, and to the north of it lies a large fresh water body, the White Lake. Since the early 1900's, the area has experienced accelerated land loss resulting from saltwater intrusion from the Gulf of Mexico. This was primarily caused by the construction of navigation channels and oil and gas access canals that acted as conduits for saltwater intrusion, and by the construction of a major highway (Highway 82) that severed freshwater supply from the White Lake. A hydrologic restoration project was proposed to increase the introduction of freshwater, sediment, and nutrients from White Lake and reduce salinity levels in the project area. The proposed restoration project includes two main components: (a) excavation of a conveyance channel to deliver freshwater from White Lake to the project area crossing Highway 82, and (b) construction of an additional control structure beneath Highway 82 consisting of four culverts. By adopting this restoration project as a student-driven module, students can perform a feasibility analysis of the project and develop a hydraulic design using data and modeling-driven learning activities.

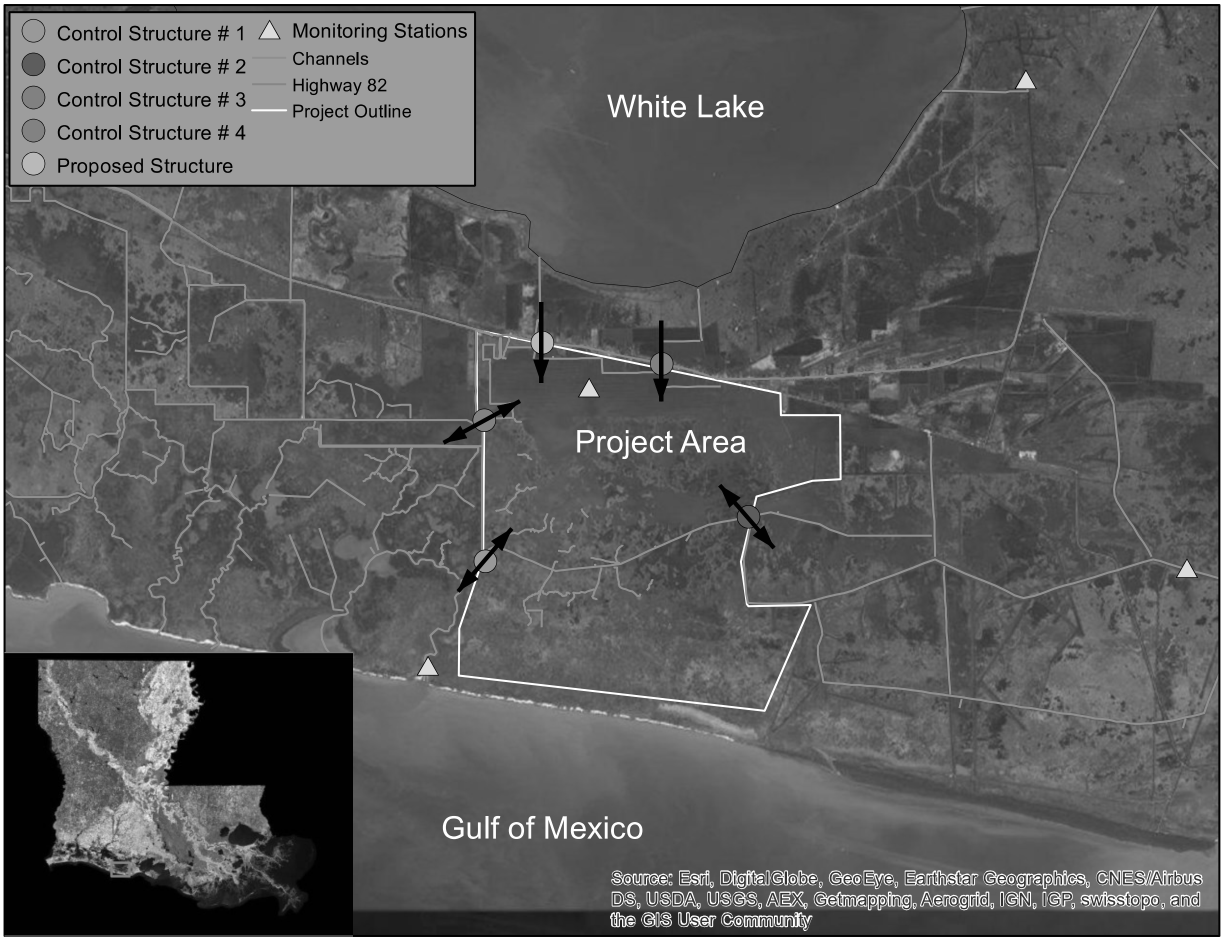

Fig. 1. Schematic map of the Pecan Island project area showing the project outline, channels, Highway 82, hydraulic structures that control water exchange and salt fluxes (circles), and observational stations used to setup and calibrate the model (triangles).

2.2. Web-Based Design with Public Accessibility

The module was developed using a web-based design where all the datasets, instructions, learning activities, and supporting materials are integrated and accessible via a publicly available web interface. The design was implemented using open-source web technologies in order to facilitate wide dissemination adaptation. Besides allowing public accessibility, the use of open-source tools will allow future users to contribute to the module by adding new datasets, changing the specifics of the case study, or adding new learning content and student learning activities. As illustrated in Figure (2), the web-based design leverages the power of geospatial visualization by embedding an interactive map within the same interface so that students can navigate project site, download data, and perform data and modeling analyses. The map component of the interface is built utilizing the open-source "OpenLayers " tools for displaying the visual component of the geospatial layers, including various embedded extensions (e.g., Geostats.js for calculating classifications of data associated with map features, Highcharts for producing and displaying various graphs and charts to the user with data loaded from map features, and Youtube IFrame API for the inclusion of informative videos and tutorials pertaining to the student activities).

Fig. 2. Web interface of module, including a collapsible "Table of Contents", a "Map" and a "Lessons" tabs. The Map tab (top panel) provides a navigable spatial display of the project area with access to different layers and downloadable datasets. The Lessons tab (lower panel) provides the contents of each section and the learning activities associated with it, detailed instructions on student tasks, a set of Help resources, and Checking-In questions with hints and immediate feedback.

2.3. Use of Free and Open-Source Engineering Analysis Tools

Consistent with the overall design criteria of the module, the student learning activities are built using three main tools that are freely accessible and easily adaptable: the EXCEL spreadsheet software, the HEC-RAS river simulation package, and the open-source QGIS geographical information systems software. Students use EXCEL to develop, implement and calibrate a mass-balance numerical model to assess the feasibility of an actual hydrologic restoration project in a coastal basin. Students gain valuable experience in basic and advanced operation in EXCEL, including complex formulas, look-up functions, if-statements, numerical solvers, and optimization algorithms. Besides its wide accessibility to educational institutions and students, EXCEL as a familiar spreadsheet program in the development of a model mitigates the amount of uncertainty that students encounter, and thus promotes confidence in their ability to succeed. Additionally, the use of EXCEL makes the model formulation and development transparent and more intuitive to students, as opposed to the more commonly used “black-box” presentations.

In this module, students use HEC-RAS to design the freshwater conveyance channel and its associated inline hydraulic structures. HEC-RAS is a river analysis software developed by the US Army Corps of Engineer’s Hydrologic Engineering Center. This industry-standard software was chosen due to (1) its free availability and version updates, which is highly desirable from a financial and logistic perspective; (2) its wide use in the engineering profession by government agencies and private firms, which can be advantageous to graduating students; (3) its ability to interface with a diverse number of other software; and (4) its user-friendly graphical interface. The easy-to-use interface, as opposed to command-line interfaces, is beneficial in educational modeling activities because it reduces the learning curve of the model, and allows focus to be centered on fundamental modeling concepts and model development (Seibert and Vis, 2012b).

The third tool used to build the learning activities is the free open source geographic information system (QGIS)., QGIS is similar to the mainstream commercial GIS software that is heavily used by the engineering and environmental firms worldwide. In the context of the module and the specific case study, students use QGIS to process digital elevation model datasets, delineate hydrologic basins, establish channel schematics and cross sections, and pre- and post-process inputs and outputs for the HEC-RAS hydraulic simulations. A detailed set of instructions, along with several tutorials and recorded screencasts, are built into the module to provide students with the basics of GIS technology and the specific tasks required to investigate the hydrologic restoration project. The use of QGIS will provide students with valuable skills in an area that is widely used in many engineering fields (hydraulics and hydrology, traffic and transportation, environmental), but without the burden of purchasing a commercial license that may not be affordable or accessible by different institutions.

2.4. Student-Support Mechanisms

Traditionally, scaffolding occurs through personal interactions between students and mentors. The scaffolding metaphor has recently been used to describe features and functionality of computer and web-based educational tools that help users complete certain tasks. To empower independent learning by students and reduce their resistance to new datasets and modeling tools, the module was designed in such a way that provides formative feedback and facilitates self-driven learning process (Figure 2). The module provides student support through a “Help Box”, which contains three features: instructional videos, templates, and rubrics. Instructional videos are used to visually demonstrate how a technique or procedure should be completed. Templates are supplied to demonstrate and promote structure and organization when students work with large data sets and model setup. To support students in completing the modeling tasks, a color-coded spreadsheet template is provided with example calculations and illustrative screencasts. Students then code the rest of the model equations to calculate water and salt exchanges for different project scenarios. Rubrics are to inform students of deliverables and demonstrate the importance of sections with respect to other sections and the module as a whole.

Other forms of scaffolding mechanisms are also seamlessly integrated into the module interface. For example, sample plots and hints are provided for key steps throughout the activity to avoid error buildup and help students proceed in the right direction. To assure students throughout the module while persistently enforcing the concept of self-learning, the module provides a series of immediate feedback mechanisms in the form of short quizzes. This is done primarily through multiple-choice, matching, and brief fill-in-the-blank quizzes referred to as “Check Your Understanding” (Figure 2). After completing the quiz, students are immediately furnished with the correct answers. Such capability enables them to review their answers and self-evaluate their understanding of the materials before progressing further. The module also includes fill-in-the-blank type questions referred to as “Checking-Ins”. While “Check Your Understandings” usually appears after a highly informative section or activity, “Checking-Ins” is usually incorporated in the middle of learning activities to ensure that students are on the right track.

2.5. Student Learning Activities

The module is composed of two phases, a feasibility analysis, and a hydraulic design. Both phases include a set of "Learning Activities" that engage students in active learning by requiring them to independently utilize datasets, apply equations, and develop models and interpret their results. Figure (3) and Figure (4) show a summary of the different sections and learning activities of each phase, the target learning outcomes, and the expected deliverables. Both phases were designed to follow stages of a typical engineering design process, including problem identification, data collection and synthesis of existing constraints, analysis, implementation, and evaluation. In the first phase, "Feasibility Analysis", students develop and apply a box model to conduct a water and salt-budget analysis and assess the feasibility of the proposed restoration project. By engaging in this phase, students learn about the main concepts of numerical models, model sensitivity, and model calibration. Using the box model, students simulate the new freshwater diversion structure and produce new water level and salinity predictions under the proposed project (see example results in Figure 5). Students evaluate the impact of the restoration project by analyzing the following questions: Does the project result in the desired salinity reduction? Is the salinity reduction significant enough from an ecosystem perspective? Is the salinity reduction significant enough from a model uncertainty perspective? Does the project have any negative impacts on the ecosystem? Students are then asked if they would be a proponent or opponent of the model adopted in the project. This is followed by a discussion of uncertainties and limitations encountered in modeling, how to determine which questions can and cannot be answered given a particular model, and what should be conveyed to clients about the model and its uncertainties.

In the second phase, "Hydraulic Design", students use the HEC-RAS software and QGIS to design the diversion channel and the configurations of the inline hydraulic structures. Starting from the existing condition model, students produce a model for the proposed diversion channel and perform a cut and fill calculation from which a cost analysis is conducted. An inline-bridge and culvert structure is then implemented in the model to simulate the construction of the new culverts underneath the highway (Figure 1). To evaluate how different channel properties can affect the channel flow capacity, students simulate different variations of channel material and roughness, channel dimensions, as well as the size, shape, and number of culverts installed under the highway. Finally, students perform unsteady flow simulations for each channel and structure configuration, and evaluate the resulting stage and flow hydrographs, plan profiles, and other key model outputs. The channel's ability to meet project goals is assessed for each channel configuration based on the total volume of freshwater introduced, number of days of freshwater introduction, and ability of the channel to handle the extra volume without flooding.

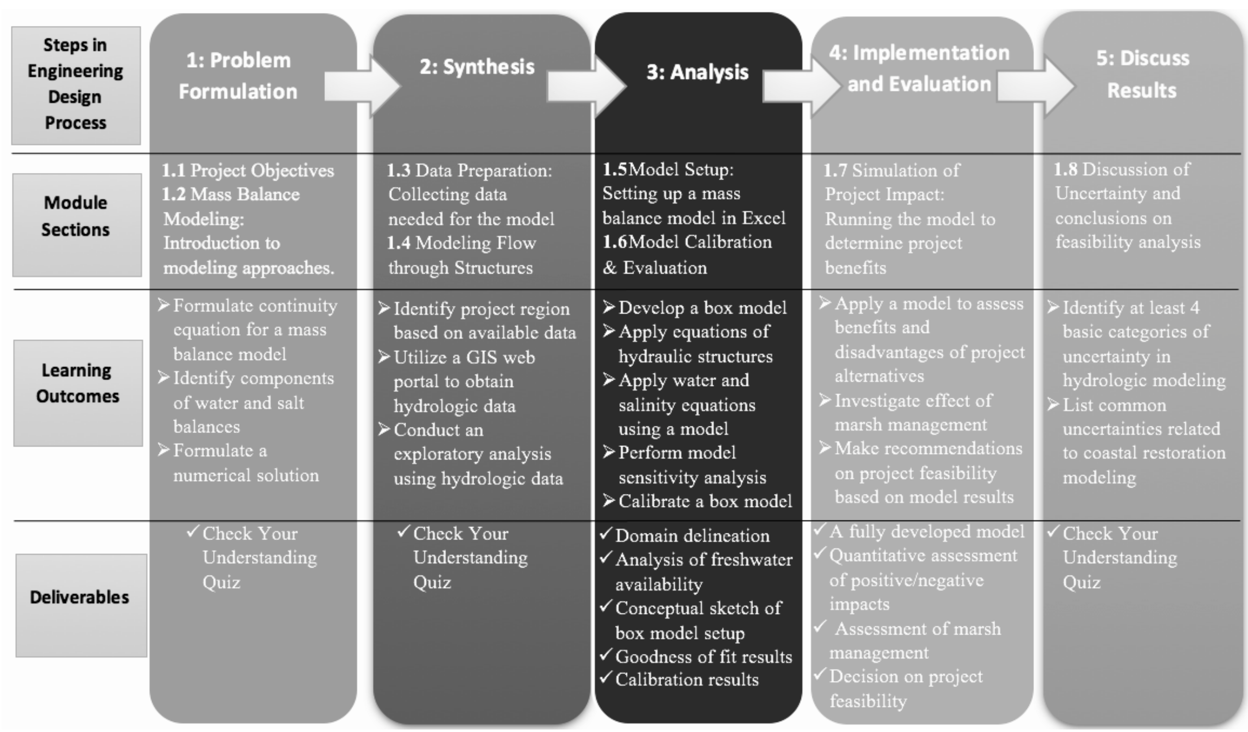

Fig. 3. An overview diagram of Phase 1, Feasibility Analysis, showing the different module sections and associated student learning activities, target learning outcomes, and expected student deliverables. The diagram also illustrates how the module sequence relate to typical steps in engineering design and analysis.

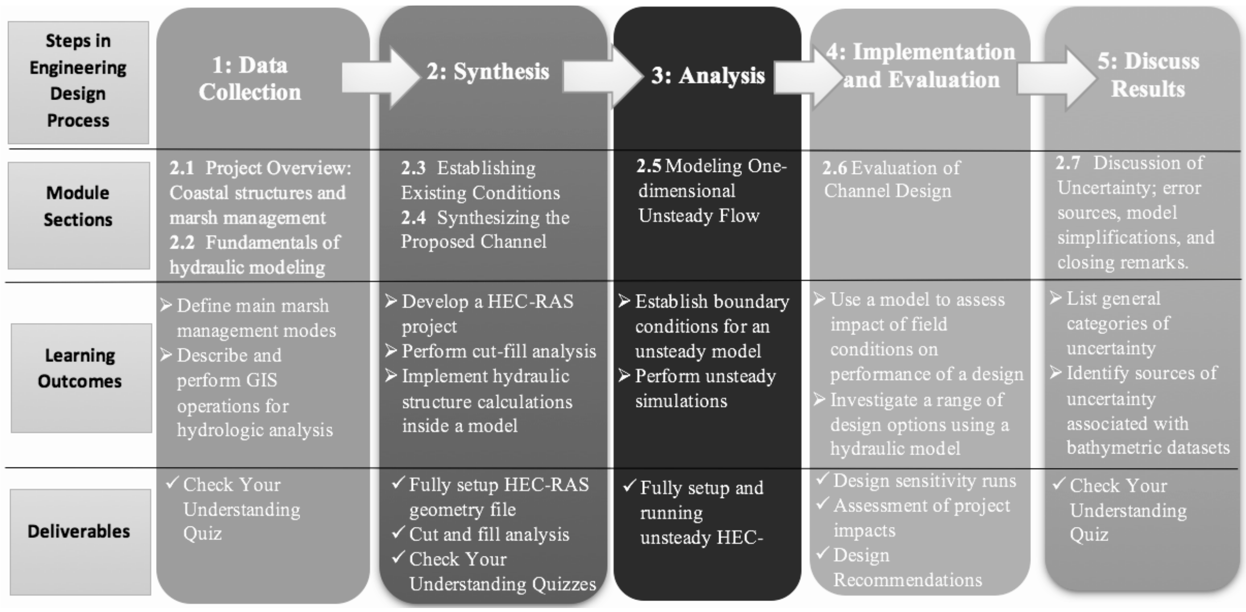

Fig. 4. Same as Figure (3), but for Phase II, Hydraulic Design.

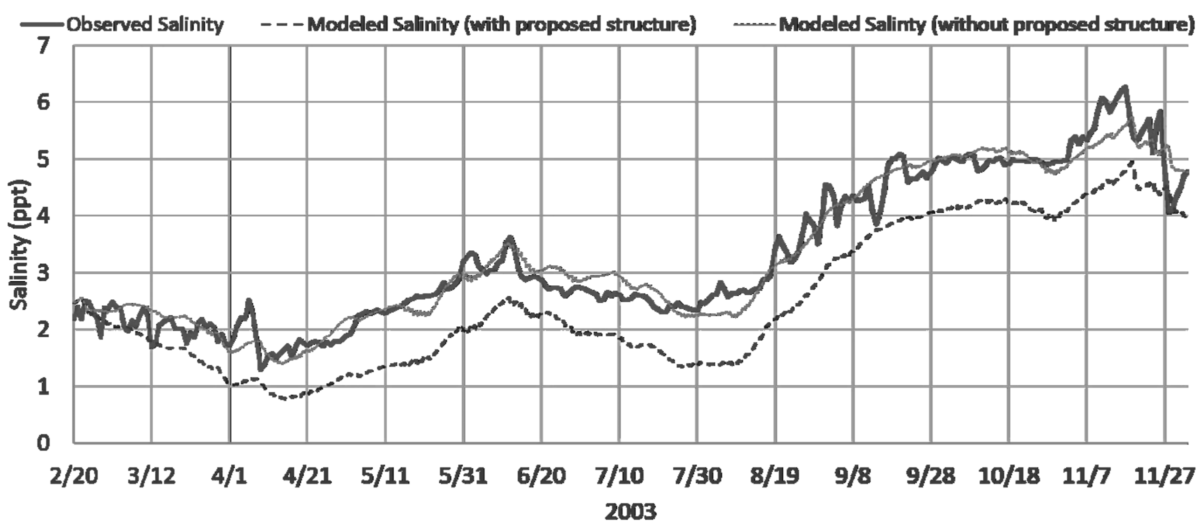

Fig. 5. Example results of students' analysis using the mass-balance model to assess predicted salinity with and without the project in comparison to observed salinity measurements.

2.6. Evaluation methods

The module was subject to several iterations of implementation, evaluation, and improvements. The focus of the evaluation was on assessing the students' perspectives and perceptions of the module in terms of its usability, how it contributes to model development and data-based skills, and the how it contributes to their interest in the field of water resources engineering and future careers. The design and evaluation of the module were guided by design-based research [16, 20] . The adoption of this approach serves two main purposes: (a) it provides solutions to problems encountered in designing and developing educational intervention, and (b) it helps identify design principles and factors that contribute to successful expansion and adoption by a multitude of users. An improvement-focused evaluation model [21] that allows for continuous identification and resolution of development problems was used as part of module assessment.

The module was implemented and evaluated in two rounds as part of two undergraduate engineering courses. The first round was conducted in a senior-level elective course on coastal hydrology consisting of 10 students. The purpose of this preliminary round of implementation was on formative assessment in which data was gathered from two sources: online student surveys where students reflected on their perceptions of the module, attributes they found valuable, and comments they wanted to share; and informal interviews with students, graduate assistant and instructor. Such qualitative data helped gain insights on how and why the module worked or failed to work and explain how and why student learning took place, and thus generate students' perspectives for module enhancement.

The second round of class implementation provided summative assessment data and was conducted in a required course on Engineering Hydraulics consisting of 29 students. The summative analysis was based on both quantitative and qualitative data. Quantitative data was based on Likert-scale responses to online student survey questions. The survey included 20 items, with a 5-point Likert scale that were mapped to answers ranging from "Strongly disagree" to "Strongly agree." The survey included several questions on students' experiences in using the datasets and modeling software, design attributes such as web-based accessibility and geospatial mapping features, help resources, and self-checking mechanisms that were embedded within the module design. In addition, the survey included a few questions on whether the module contributed to their appreciation of the use of numerical models in hydrologic analysis. Finally, the survey gathered students' overall perceptions on how the module fits with the course and whether the module's heavy data and modeling components have interfered with their learning. Text fields were added at the end of the surveys for students to enter additional comments they may have. The survey questions were occasionally followed by a set of informal interviews with the students and the teaching assistant to provide further insights on specific students' responses to the survey questions [22].

3. Results

3.1. Evaluation Results

3.1.1. Student Perception of Module Usability

Formative evaluation data on module usability indicated that while students enjoyed the module as a supporting tool for the class, they reported some problematic areas in the module (e.g., confusing calculations; complex spreadsheet coding). Students commented that the project was not easy to implement without clear instructions and that they would favor specifics in the data analysis and modeling tasks. They would like to have some feedback mechanisms to avoid the ripple effect of error-buildup. Based on the results of the first round of evaluation, we conducted frequent periodic reviews of the user interface from a student perspective and implemented a major re-design of the module. First, the overall format of the module and its hierarchy was revised to follow a well-structured flow where each section is composed of the following sub-sections: a summary; background information on the theory and methodologies; a multiple-choice quiz assessing students' understanding of basic concepts covered in the background section; and a set of learning activities with clearly defined and illustrated textual and graphical instructions along with what students are expected to complete and submit for evaluation. The second set of revisions focused on adding more mechanisms for student support and just-in-time help, including the following: specific task instructions to alleviate student confusion and anxiety; a help toolbox to provide supportive links such as downloadable resources and how-to video tutorials; spreadsheet templates posted on the site to provide students with a guided structure on how to set up and implement the model.

Following these revisions, a summative evaluation phase was conducted, and according to the survey results (Table 1), students cited the following module attributes as most helpful:

(a) Video Tutorials and other supporting figures: Students perceived that tutorials were instrumental to their understanding of the concepts and served as guidance to successful completion of their tasks. They also indicated that other visual elements (e.g., graphical illustrations, example graphical results) helped them visualize the problem solving process. One student responded by saying "The videos and pictures lessened the possibility of error and allowed us to spend more time comprehending and analyzing the material; without these attributes the project would not be an effective 'self-learning' module."

(b) Checking-In Questions: Students emphasized the value of these interactive questions as a mechanism that provided immediate feedback to confirm their learning and identify any informational gaps before they move to the following sections.

(c) Interactive Map: Similar to the commonly used web map apps, students perceived that it helped them keep a continuous sense of context, visualize the different components of the proposed project, and access necessary datasets.

(d) Synthesis Questions: While students showed appreciation for the detailed step-by-step instructions, they commented that without the synthesis questions at the end of the module the overall objective of the proposed project would have been lost. They methodically followed the instructions without the big picture or end goal in mind until posed with the synthesis questions which prompted them to reflect upon what they had done and for what purpose.

Meanwhile, students offered their suggestions for further usability improvement. First, overwhelmingly, students requested that more video tutorials and screenshots should be included to supplement the instructions. Second, students suggested that enhanced self-check-ins be provided to avoid the irreversible error buildup at the latter stage of the project. The graduate teaching assistant, who participated in developing the module and in administering it to the class, had similar perceptions for improvement. He contemplated on the proper combination of support mechanisms that might work best for students with different learning styles (e.g., video tutorials and screen captures, coupled with textual description and detailed step-by step instructions). He also considered lowering the scope of the vocabulary in the instructions to make them appropriate for inexperienced undergraduate students new to the area of numerical modeling.

Table 1. Student Survey Results on Module Usability

1.	How do you like the overall design of the Module interface and its main elements (Table of Contents, Map tab, and Lessons tab)? (Don't like it …Like it very much)	4.28
2.	Rate the helpfulness of the "Checking-In" questions in the middle of each section (Not helpful at all … Very helpful)	4
3.	Rate the helpfulness of the Check Your Understanding question sections at the end of each section (Not effective at all … Very effective)	3.76
4.	Rate the helpfulness of the interactive Module map (indicated by the red "Map" tab on the main page of the module) (Not helpful at all … Very helpful)	3.90
5.	Rate the helpfulness of the "Help" toolbox that contains ("Videos" and "Templates") for understanding and completing the module tasks (Not helpful at all … Very helpful)	3.72
6.	Provide examples of specific Module attributes that you liked the most.	

3.1.2. Student Perceptions of Module Contribution to Learning

Survey results (Table 2) showed that students perceived that the module moderately contributed to their learning on how to perform various hydraulic tasks. For example, they indicated they could comfortably set up a HEC-RAS hydraulic model (Likert rating 4.08), perform hydraulic simulations and interpret model results (3.69), somehow identify strengths, weaknesses, and limitations of hydraulic models (3.31), and comfortably describe basic vocabulary used in hydraulic analysis and modeling (4). Students also found it fairly easy to use some industry-standard tools and software such as GIS (3.73), HEC-RAS (3.12), and Lidar data (3.85). The three moderate ratings related to tools and software echoed students' suggestions for more video tutorials, screenshots, and crystal clear instructions to guide their task accomplishment while applying them. Though several students had difficulties in completing some of the modeling tasks, especially those that involve programming aspects. These difficulties were mainly attributed to students' lack of programming skills, indicating that it might be a critical challenge for introducing modeling-based activities.

A critical aspect of evaluating student learning using data and modeling-based material is whether students can transfer the learning outcomes and skills gained from a particular project into other hydrologic settings. An explicit assessment of such aspect is not trivial and may require, for example, that the module be applied in a whole new case study in a different basin to gauge students' abilities to successfully formulate and analyze the newly posed hydrologic problem. While this is clearly beyond the scope of this study, the surveys conducted after the completion of the module provided some insights in the transferability of students' learning (Table 3). After being exposed to the module, students perceived that they were moderately confident in their capability in completing the key tasks of this module in other projects or in other locations (3.62); the hands-on experience with the module, to some extent, helped build their skills to develop numerical models and interpret their results (3.5); and they perceived that they feel confident in applying numerical modeling concepts and tools after graduation at their first job (3.96).

Table 2. Student Survey Results on Student Perceptions of Module Contribution to Learning

1.	Describe goals of a freshwater introduction project within a coastal ecosystem. (Didn't contribute at all … Contributed significantly)	3.85
2.	Setup HEC-RAS model, including geometry, boundary conditions, channels and structures for a project of interest. (Didn't contribute at all … Contributed significantly)	4.08
3.	Perform hydraulic simulations and interpret model results. (Didn't contribute at all … Contributed significantly)	3.69
4.	Identify strengths, weaknesses, and limitations of hydraulic models. (Didn't contribute at all … Contributed significantly)	3.31
5.	Describe basic terms and vocabulary used in hydraulic analysis and modeling. (Didn't contribute at all … Contributed significantly)	4.0
6.	Rate the following hydraulic analysis tools (Not easy to use … very easy to use) QGIS; HEC-RAS; LiDAR data downloader	3.73, 3.12, 3.85

Table 3. Student Survey Results on Potential for Learning Transferability

1.	How confident do you feel about being able to complete the key tasks of this project in other projects/locations (Not confident at all … Very confident)	3.62
2.	This module improved building my skills to develop and use numerical models" (Don't agree … Strongly agree)	3.5
3.	This project has been effective in introducing me to numerical modeling concepts and tools to the extent that I will be less timid using them after graduation (at your first job). (Don't agree … Strongly agree)	3.96

3.1.3. Student Receptiveness to Module and their Interests

A set of informal interviews were conducted to gain a direct insight into students' overall impression of the value of the module in this class and for their future career. Overall, students appreciated the privilege of being immersed in a computer-based learning environment, getting exposed to modern software and tools, and being able to synthesize the different components covered in the class. A majority of the students regarded the amount of details and procedural calculations overwhelming, but worthwhile from a learning experience perspective. They perceived that the module enabled them to gain insight into water engineering concepts learned in the class and apply them in real-world projects. Students also appreciated the opportunity where they could put together their technical knowledge to address real-world water problems native to the region. These perceptions were also evident in the student surveys (Table 4). Students indicated that utilizing local real-world projects can support their learning beyond traditional textbook problems (4.55), serve as a meaningful supplement to classroom instruction (4.12), and enhance their interests in the field of water resources engineering in general (3.96). Students strongly agreed that the use of models and datasets was conducive to their learning process (4.17), and did not interfere with their overall learning process (2.62).

Meanwhile, students shared some factors that might have hindered their learning gain, mainly on the timing of introducing the module and the time allotted for students to complete the learning activities. Although they perceived the project should be done toward the end of the semester after being exposed to all concepts, they felt being rushed through the activities, stressed out, and frustrated when extra guidance was needed. Because of the time constraints, some felt that they lost the opportunity to synthesize and reflect on their learning. All of these might have helped explain the relatively low performance in students' last project submission, as compared to the performance achieved in their first two submissions. They recommended that the module be introduced earlier in the semester, and carried out throughout the semester to allow them enough time for learning. This module was assigned to the students as an independent, self-driven project over a period of three weeks, one week for each pair of sections. The relatively short time was intentional so that the integrity of the module and its problem- and project-based value is not lost because of its being spread over a long time. Keeping the overall time to completion relatively short was important so that students did not lose the overall goal of the project. Nevertheless, we noticed that students needed more time to reflect on their results and synthesize them into useful results, and possibly make revisions and corrections to their data and models. This was also echoed by the graduate teaching assistant during one of the interviews who indicated that when students feel limited on time, they simply state the obvious facts from the datasets and graphs, but not necessarily what they mean in an actual hydrologic sense.

Table 4. Student Survey Results on Student Receptiveness to Module and its Overall Value

1.	This project has provided a more practical application compared to traditional course work. (Don't agree … Strongly agree)	4.55
2.	The use of models and datasets as was done in this project has been conducive to the learning process. (Don't agree … Strongly agree)	4.17
3.	The use of models and datasets as was done in this project has interfered with your overall learning process. (Don't agree … Strongly agree)	2.62
4.	This modeling experience improved my interest in the field of water resources engineering in general (Don't agree … Strongly agree)	3.96
5.	This modeling-based project has been a valuable component to this course (Don't agree … Strongly agree)	4.12

4. Discussion

Learning is a process that involves multifaceted changes in student attitudes, beliefs, capabilities, knowledge structures, mental models, and skills. Technologies as evidenced in this study alone will not adequately contribute to students' understanding and performance in hydrologic/hydraulic problem solving. What matters more is how technologies are pedagogically applied in the learning environment. Although technology-enhanced pedagogies have not yet been widely embraced in higher education [23], the design, development, and implementation of our modeling case study will hopefully shed some light on how judicious technology-enhanced pedagogies can exert its potential in helping students not only enrich their learning experiences, but also enhance their academic performance and interest in future careers in the field. As pointed out by Borrego et al., (2010), student resistance was a consideration in faculty's decisions to adopt a certain engineering learning innovation.

The research findings in this study were generated from data including Likert-scale surveys, informal interviews, and text-response surveys. The study primarily reveals students' perceptions of the module's usability, as well as its potential in enhancing students' knowledge transfer and learning gain in hydrology. However, because of the design-based research focus, the study did not explicitly address module impact on achieving or improving students' learning outcomes in a quantitative fashion exemplified by, for example, control-treatment evaluation. Future efforts will focus on addressing this important evaluation aspect of modeling-based learning innovations. We also plan to conduct qualitative research examining how and why the modeling-enhanced pedagogy improves students' learning in the field of hydrology and water resources engineering classes. While the current study focused on student-related factors in terms of usability and potential resistance, faculty-related factors are equally important. According to the survey conducted on engineering departments in general [18], faculty issues play a more complex role in how educational innovations are adopted. Therefore, future studies should focus on addressing important faculty limitations such as the time required to prepare or manage new innovations, especially those that require labor-intensive efforts such as the case for modeling and data analysis, and a better understanding of the types of faculty-support mechanisms that can potentially reduce their own resistance to developing and adopting new teaching innovations and tools in water resources engineering. Another aspect of future expansion should focus on promoting the collaborative development of project-based learning resources. The module developed in current study was built using a web platform that provides access to instructional content, datasets and the modeling tools. However, the current design doesn't allow for independent adopters to modify or contribute to the existing content. Future phases on our study will develop a collaborative online platform that facilitate co-development, sharing and wider dissemination of innovative resources, and thus unlock the true values of open-source cyberinfrastructure technologies for the benefit of the global educational community.

5. Conclusions

This paper presented the design, evaluation, documentation and reflection of a web-based undergraduate engineering learning module that focuses on the use of numerical modeling to analyze and design water resources engineering projects. Overall, the project-based, technology and data-driven pedagogy enriched students' learning experiences and enhanced their academic interest in the subject matter. However, our study indicates the importance of addressing usability and student-support issues in order to increase students' ability to work on activities independently, reduce their resistance to the new material, and thus eventually increase the instructor's interest and commitment to integrate such resources into the undergraduate curriculum. Design principles are needed to address unresolved methodological issues in design-based research. Based on the findings of our study, we formulated the following design principles with the intention to guide instructors/researchers interested in developing modeling and data-driven, technology-enhanced learning materials that use open-access resources in the field of hydrology and water resources engineering:

(a) Principle 1: Develop technical content with a well-balanced coverage that includes informational background, clearly-defined instructions to the user as to how to implement the different tasks, procedural specifics in detailed fashion as needed, but without compromising the student-centered discovery aspects of material.

(b) Principle 2: Provide seamless integration of student interactive feedback mechanisms throughout the module to facilitate their progress through the complexities inherent with data analysis and modeling tasks. This design principle is especially important for two aspects: (1) it can reduce the burden on instructors who decide to adopt the new resources, and as such enhance potential for dissemination and independent adoption, and (2) it can enhance students' experience in using free and open-access engineering analysis tools (e.g., software) and compensate for the typical lack of user support mechanisms that are mostly available in commercial packages.

(c) Principle 3: Provide multifaceted just-in-time support mechanisms in various modalities within the module to engage students and support their independent learning, for example, text-based instruction, screen captures, video tutorials, and audio explanation. The purpose of these support mechanisms is to enrich students' learning experiences and enhance their learning performance - the greater the integration of various mechanisms within the computer-based learning environment, the fewer breaks in context, and thus the greater the potential improvement in efficiency and effectiveness of students' learning.

(d) Principle 4: Provide synthesis-type learning activities and questions to support student reflection of the overall purpose of the analysis, ensure higher-order learning outcomes, and avoid potential of students getting overwhelmed with fine details and procedural steps, typically encountered in engineering modeling-based analysis.

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