Special Issue on Education, Outreach and Citizen Science Initiatives Underpinned by Coastal and Shelf Processes Research

Title: Fostering science-to-civics literacy through the development and assessment of a sea-level rise curriculum.

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Highlights

- Researcher and educator collaboration was essential for curriculum development.
- Translation of coastal processes research reached unengaged student audiences.
- Sea-level rise curriculum enhanced educators' knowledge.
- Sea-level rise curriculum led to positive student behavior change.

Keywords
Experiential learning, climate change, environmental education, Gulf of Mexico, resilience, interdisciplinary

Abstract

Coastal communities are at risk to current and future sea-level rise (SLR) impacts, such as increased erosion and more frequent high tide flooding. In the northern Gulf, these impacts are exacerbated due to a confluence of socioeconomic issues, making it harder to plan for and adapt to changing conditions. To break through barriers to action, education of coastal residents and youth about future impacts must be undertaken. We worked with a team of researchers and educators to develop a four-module curriculum addressing sea-level rise impacts and community solutions. Module content was informed using the most recent advancements in coastal and estuarine research by collaborating with researchers active in those fields. The curriculum was launched to educators through professional development workshops and tested in classrooms to adaptively incorporate feedback into the final product. The process to collaborate with educators and researchers led to the successful development of a usable and useful curriculum. Students engaged in the curriculum indicated doing more sustainable actions and demonstrated knowledge gains. Educators who participated in trainings and/or testing the curriculum indicated they were more confident teaching SLR-related concepts and also demonstrated knowledge gains. The curriculum can be used widely, and the process can be replicated for other curriculum development in different regions.

1. Introduction

Coastal communities around the globe are already experiencing the impacts of climate-driven changes in global sea level (Nicholls 2011). Future sea-level rise (SLR) projections indicate these trends will worsen and increase the vulnerability of coastal communities (Oppenheimer and Hinkel, 2019). These trends are evident along the northern Gulf of Mexico (nGoM) where relative SLR (RSLR) is significantly higher than the global average. Combined with low-lying topography and rapid development, SLR is exacerbating physical hazard vulnerability in the nGoM (Coastal County Snapshots, 2017; Martinich et al., 2013; Surging Seas Risk Finder, 2018). These factors expose the region to impacts such as increased flooding events (Sweet et al., 2018), intensifying storm surge (Bilskie et al., 2016), and increased damage to infrastructure (National Research Council, 2014).

The nGoM experiences a confluence of socioeconomic challenges, including vulnerable industry, low per capita income, and low educational attainment (Fleming et al., 2018; Martinich et al., 2013; Sweet et al., 2017). An average of 79% of the population at risk to sea-level rise in Alabama and Mississippi are also in a high or medium level of social vulnerability (Surging Seas Risk Finder, 2018), indicating residents and communities along the nGoM have fewer resources to adapt to SLR (Martinich et al., 2013). Areas of higher vulnerability are more likely to be abandoned than protected in response to SLR; 99% of the most socially vulnerable people living along the Gulf are living in areas at risk of abandonment (Martinich et al., 2013). These communities face the combined impacts of socioeconomic challenges and increased physical hazards, and without the knowledge and resources necessary to mitigate and adapt, they will be negatively affected economically, ecologically, and culturally.

The leaders and residents of coastal communities cannot pursue effective SLR resilience if they do not adequately understand the risks and available solutions. SLR is poorly understood by non-technical audiences; therefore, it is not prominent in coastal decision-making or the broader coastal community consciousness (Akerlof et al., 2017; National Academies of Science, Engineering, and Medicine, 2017; Shao & Goidel, 2016). Difficulty in understanding SLR science and perceiving it as a future threat rather than a current one impedes coastal residents from making informed decisions (Covi & Kain, 2016). Successful adaptation to SLR will require a societal approach utilizing a suite of creative and holistic actions by residents and decision-makers (Aldrich, 2018). However, stakeholders have identified both individual and societal barriers to action around climate change. Some individual barriers include lack of knowledge of the causes, impacts, and solutions to SLR, as well as a sense of helplessness. Perceived societal barriers include lack of political action, social norms and expectations, and a lack of enabling initiatives (Lorenzoni et al., 2007). Along the nGoM, residents' perceptions of the threat of SLR are more influenced by partisan affiliations than objectively measured conditions (Shao and Goidel, 2016). Additionally, local officials are best suited to take adaptive action, yet they are reluctant to act if their perception of SLR risks are uncertain (Bulla et al 2017). Providing residents and coastal decision-makers across sectors with the ability to address these complex socio-environmental issues could help overcome some of these aforementioned barriers.

Engaging and educating coastal residents, including children and students of all ages, fosters an empowered and action-seeking community for SLR resilience that can undertake successful efforts (Lorenzoni et al., 2007). Educators are interested in integrating climate and SLR science in their courses, but often cite uncertainty in data sources, lack of confidence in climate science fundamentals, and minimal available resources as barriers to adjusting their curriculums (Plutzer et al., 2016; Turner, 2016). This gap in education generates coastal residents that lack a comprehensive understanding of ongoing changes that directly and indirectly impact their well-being (Plutzer et al., 2016). Professional development with educators increases knowledge and increases teacher confidence in integrating curriculum activities into their classroom (Garet et al., 2001). Providing educators proper training and access to a hands-on, comprehensive SLR curriculum built in collaboration with formal and non-formal educators can reduce barriers to integrating climate science into the classroom.

Effective climate change communication relies on emphasizing solutions and providing actionable steps (Moser and Dilling 2007; Moser 2014). Framing climate change and SLR with too much focus on the large and future scale impacts can increase feelings of hopelessness and anxiety, leading to further inaction (Doherty and Clayton 2011; Ojala 2012; Clayton, Manning, and Hodge 2014). By highlighting straightforward solution pathways and empowering youth with the knowledge and skills to navigate complex interactions, we can instill confidence in our future leaders, empowering coastal residents to make changes (Clayton, Manning, and Hodge 2014; Kretser and Chandler 2020).

The goal of our project was through a co-developed SLR curriculum to foster an informed and prepared coastal citizenry that possesses the necessary skills and understanding of critical coastal processes to reduce coastal vulnerability to SLR. This paper reviews the process and results of developing and assessing a high school curriculum with input from educators and scientists and provides a finalized curriculum with best practices for adapting the process to other regions and topic areas.

2. Material and methods

We developed a curriculum focused on SLR resilience for Mississippi and Alabama high school teachers through an iterative process with a Project Team, a panel of advisors, and local educators.

2.1 Geographic focal area

Coastal Mississippi and Alabama are demographically and socio-economically diverse. Within a five-mile radius, census tract level median household incomes can range from less than $20,000 to more than $80,000 (National Ocean Service, NOAA, 2011). Similarly, the proportion of students eligible for free lunch and the racial makeup varies tremendously (U.S. Department of Education, 2020). That diversity is represented in this project through the collaboration with educators from the coastal counties of Mississippi and Alabama and the inclusion of representatives from affluent and poorer regions.

2.2 Project Team and Advisory Panel

The Project Team members are actively involved in the rapidly evolving fields of study around coastal and estuarine processes, including SLR impacts, flooding, and natural and built infrastructure approaches to adaptation (Table 1). Areas of study by the Project Team include research with coastal communities to develop adaptation pathways that maximize resilience and minimize resource needs, numerical modeling of coastal dynamics and shoreline changes due to coastal processes such as waves, tides, currents, and SLR, analyses of habitat response to coastal hazards, application of natural and nature-based features for shoreline and flood protection, and community planning for resilience. The Project Team also had members representing a variety of education approaches through traditional classrooms and non-formal education settings.

An Advisory Panel consisting of fourteen science and social studies educators from coastal Mississippi and Alabama was formed to guide the curriculum development (Table 1). They represented educational institutions including public school districts, environmental education centers, National Estuarine Research Reserves, and Extension offices, and represented positions from classroom teacher through curriculum coordinator and director. Virtual meetings were held from March through December

2019, with the first six months focused on curriculum development leading up to the Educator Workshops and the final months to review revisions made based on workshop feedback.

Table 1. Expertise and experiences of project collaborators.

Institution	**State**	**Subject**	**Expertise**	**Project Participation**
Alabama School of Math and Science	AL	Science	Environmental science education	Project Team, Pilot-Test, Beta-Test
Mississippi State University Coastal Research and Extension Center	MS	N/A	Coastal ecology	Project Team
Program for Local Adaptation to Climate Effects: Sea-Level Rise	MS, AL, FL	N/A	SLR extension	Project Team
Program for Local Adaptation to Climate Effects: Sea-Level Rise	MS, AL, FL	N/A	SLR extension and education	Project Team
University of South Alabama	AL	N/A	Coastal engineering and modeling	Project Team
Dauphin Island Sea Lab - Discovery Hall Programs	AL	Science	Non-formal education	Project Team
Mississippi-Alabama Sea Grant Consortium	MS	N/A	Community planning for resilience	Project Team
Oak Grove High School	MS	Science	Classroom science teacher, Zoology class	Pilot-Test, Beta-Test
Gulf Shores High School	AL	Science	Classroom science teacher, Marine Biology class, Gulf Coast Ecology Class	Pilot-Test, Beta-Test
Pascagoula High School	MS	Social Studies	Classroom social studies teacher, Local Culture class	Pilot-Test, Beta-Test
Daphne High School	AL	Science	Classroom science teacher, AP Environmental Science class	Pilot-Test, Beta-Test
Alma Bryant High School	AL	Science	Classroom science teacher, Marine Biology class	Pilot-Test
Ben C. Rain High School	AL	Science	Classroom science teacher, Earth and	Pilot-Test

			Space science	
Our Lady Academy	MS	Science	Classroom science teacher, Biology class	Pilot-Test
Mobile County Public School System - Continuous Learning Center	AL	Science	Classroom science teacher, Physical Science class	Pilot-Test
Gautier High School	MS	Science	Classroom science teacher, Earth Science class	Beta-Test
Chickasaw High School	AL	Science	Classroom science teacher, Biology class	Beta-Test
Murphy High School	AL	Science	Classroom science teacher, Honors Marine Biology class	Beta-Test
Pass Christian High School	MS	Science	Classroom science teacher, Environmental Science class	Advisory Panel, Pilot-Test, Beta-Test
Alma Bryant High School	AL	Science	Classroom science teacher, Environmental Management class	Advisory Panel, Beta-Test
Daphne High School	AL	Social Studies	Classroom social studies teacher	Advisory Panel
Weeks Bay National Estuarine Research Reserve	AL	Science	Non-formal education	Advisory Panel
Grand Bay National Estuarine Research Reserve	MS	Science	Non-formal education	Advisory Panel
Mississippi State University Extension - Jackson County	MS	Science	4-H coordinator	Advisory Panel
Gulf Coast Research Laboratory Marine Education Center	MS	Science	Non-formal education	Advisory Panel
Ocean Springs High School	MS	Science	Classroom science teacher	Advisory Panel
Pascagoula-Gautier School District	MS	Science	Science curriculum coordinator	Advisory Panel

Florida Fish and Wildlife Conservation Commission	FL	N/A	Curriculum development	Advisory Panel
Mobile County Public School System	AL	Social Studies	Social studies curriculum supervisor	Advisory Panel
Grand Bay National Estuarine Research Reserve	MS	Science	Non-formal education	Advisory Panel
Mobile County Public School System	AL	Science	Science curriculum coordinator	Advisory Panel
Mobile County Public Schools' Environmental Studies Center	AL	Science	Non-formal education	Advisory Panel

2.3 Curriculum development

Four modules were determined at the outset of the project by the Project Team: 1) SLR and Flooding Basics, 2) Natural Solutions, 3) Ordinance and Policy Solutions, and 4) Community Planning. Content learned in the four modules culminated in a student Capstone Project where students developed their own resilience plan for a fictional town. The projects were then entered into a state-wide competition and finalists participated in a state-wide Hazard Summit. The Project Team synthesized recent coastal science and climate change research and outreach, extension, and educational material to develop the outline for the curriculum. Specific learning objectives for each module were developed to scope the material for the curriculum.

The Project Team and Advisory Panel worked through an iterative process over a six-month period to develop and refine the first draft of the curriculum (Fig. 1). This draft was presented to regional coastal educators through two workshops, one in coastal Mississippi and another in coastal Alabama, to introduce them to the curriculum as a resource, and to collect feedback for further refinement of the curriculum for classroom use (Vedral, 2021). Workshop participants represented science and social studies educators from private and public high schools and informal education centers. The workshops were held on weekdays and attending educators were provided meals, a $100 stipend to cover travel or substitute teacher expenses, as well as Continuing Education Units (CEUs). Workshop participants were offered the opportunity to Pilot-Test the curriculum that included an additional $800 stipend.

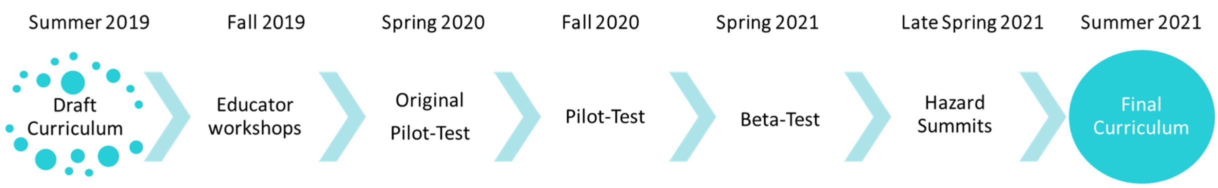

Figure 1: Timeline overview of the project development.

After refinement of the curriculum based on workshop feedback, the curriculum was evaluated in the classroom by students and teachers. Teachers were selected from the list of workshop attendees to pilot-test the curriculum in the spring semester of 2020. These educators were assigned to use

Module 1 plus another module with their students. Due to COVID-19 impacts and the move to virtual learning, the Pilot-Test was restarted with teachers in the fall of the 2020 – 2021 school year. Teachers and students provided feedback, and updates were made to implement the curriculum in classrooms through a Beta-Test. A mix of returning and new teachers participated in the Beta-Test in the spring semester of the 2020 – 2021 school year where they used all four modules and had students conduct a capstone project. The curriculum was used in science and social studies classes including: Marine Biology/Science, Botany, Local Culture, Advanced Placement (AP) Environmental Science, Earth and Space Science, Biology, and Environmental Management. The classes spanned grades eight through twelve. School locals ranged from midsize city to rural, with representation of Title I and low-income schools. The top student capstone teams from each Beta-Test school were selected to present their projects at one of two state-specific Hazard Summits. Student teams gave a 10-minute presentation with their designed resilience strategy. Local resilience professionals were invited to judge the presentations as well as engage with students during small group discussions to foster a sense of inclusion with the coastal hazards community. Through the small group discussions students were exposed to different science and resilience career opportunities. Project Team members and local resilience professionals scored the students using a rubric (Appendix A) on effort, description, depth of background research, clarity, and defense with a max possible score of 35 points. Feedback and evaluation data were collected, and final revisions were made to the curriculum. The final version of the curriculum is freely available online through a variety of partner and Project Team curriculum host websites (Vedral et al., 2021).

2.4 Evaluation

The curriculum was evaluated at multiple steps during its development to shape content and assess effectiveness. The Advisory Panel completed real-time polling in meetings and online evaluation surveys and submitted comments via email. The education workshop participants were given pre- and post-tests on their climate and SLR knowledge, completed evaluation surveys, and provided oral and written feedback (Vedral, 2021). Students participating in the Pilot-Test and Beta-Test were given digital pre- and post-tests to assess knowledge gained and behavioral changes (Appendix B). All educators in the Pilot-Test and Beta-Test completed evaluations via an online survey instrument to collect feedback on the curriculum ease of use, importance, content, and educator knowledge change. Four Pilot-Test teachers were randomly selected to be interviewed to further explore and understand what aspects of the curriculum were successful and how the curriculum could be improved moving forward. All online/digital tests and surveys were administered via Survey Monkey.

Initial data trends were examined and identified using basic descriptive statistical summaries (i.e., percent correct vs. incorrect, percent change in responses). The overall trends and results of the pre- and post-tests were analyzed and assessed using McNemar tests for content questions (i.e., comparing correct vs. incorrect responses per individual student) and McNemar-Bowker tests to investigate shifts in behavior or concerns towards SLR. Where McNemar-Bowker failed, exact tests were used. The results of the McNemar tests determined if there was a statistical difference ($p < 0.05$) in the proportion of correct responses from pre- to post-test. Initial data trends were then examined to determine the direction of this change in knowledge (i.e., did the proportion shift from more incorrect to correct responses or vice versa). Data were analyzed in Rstudio (version 1.3.1093, R Core Team, 2020).

3. Results

3.1 Curriculum content, and structure

The developed curriculum was named *Sea-Level Rise in the Classroom* and is composed of four modules and a capstone project that can be used in science or social studies high school classes (https://placeslr.org/our-products/sea-level-rise-curriculum/). Each lesson is divided into the 5E Model of Instruction with sections Engage, Explore, Explain, Elaborate, and Evaluate, and includes background material, readings, supplemental videos, student work pages, and hands-on activities.

Module 1: Sea-Level Rise and Flooding Basics has four lessons that address the science behind sea-level rise and coastal flooding. Objectives for Module 1 focus on providing foundational understanding to support the remaining modules. These topics include understanding the definition of sea level, the processes driving SLR, thermal expansion of water and land-ice melt, and the effects of SLR on exacerbating existing flood hazards through a multitude of coastal processes.

Module 2: Natural Solutions has three lessons that cover natural solutions as a pathway toward community resilience. The objectives for Module 2 highlight the resilience and functionality of natural coastal ecosystems and how to use these characteristics in planning and preparing for hazards. These topics include understanding the tidal cycle, wetland function, and green infrastructure.

Module 3: Ordinance and Policy Solutions has three lessons to allow students to investigate the role of policy and ordinances as a pathway toward community resilience. Module 3 exposes the students to decision-making at the municipal level and outlines the use of floodplain management practices and policies into local planning and development practices.

Module 4: Community Planning has three lessons that bring the solutions-based content together via community planning. The concluding Module 4 showcases diverse ways communities can integrate SLR resilience into planning and the importance of multiple perspectives.

Following a cross-curricular approach, the lessons meet the Next Generation Science Standards (NGSS Lead States, 2013) and Ocean Literacy principles (Ocean Literacy, 2005) as well as state science and social studies standards. The curriculum materials for activities in the classroom include instructional scaffolding such as online resources, worksheets, videos, and background information to support an inquiry-based learning approach. These materials are hierarchically organized into basic or extension, enabling educators the flexibility to collapse or expand the modules depending on their available time and classroom structure. Materials to support enrichment activities include lab protocols that can be conducted in the classroom as well as recommended field trips and listed potential guest speakers.

In addition to the four modules, the curriculum culminates in a capstone project where the students apply their learned knowledge to develop a resilience approach focused on SLR for a fictional town. Two towns were developed for the project with interactive StoryMaps (Waterside Village: https://arcg.is/0j5eyC and Sunrise Bayou: https://arcg.is/1K8KCq) to display a town description, population density, income distribution, socioeconomic statuses, cultural and historic points of interest, critical infrastructure, and vulnerabilities due to SLR and storm surge. These towns have fictional names "Waterside Village" and "Sunrise Bayou" to reduce bias but are based on real locations representative of the nGoM. The final version of the curriculum including the capstone project is available online (Vedral et al., 2021).

3.2 Educator Workshops

Fifty-five educators from forty-one educational institutes participated in the two educator workshops. Educators represented formal education in private schools, public schools, and non-formal educators from research reserves or aquariums. A majority of educators (64%) were from public schools. Of workshop participants, 87% strongly agreed that "participating in this workshop was a good use of my time" and 91% strongly agreed that "this workshop increased my understanding of the Sea-Level Rise in the Classroom curriculum." (Fig 2).

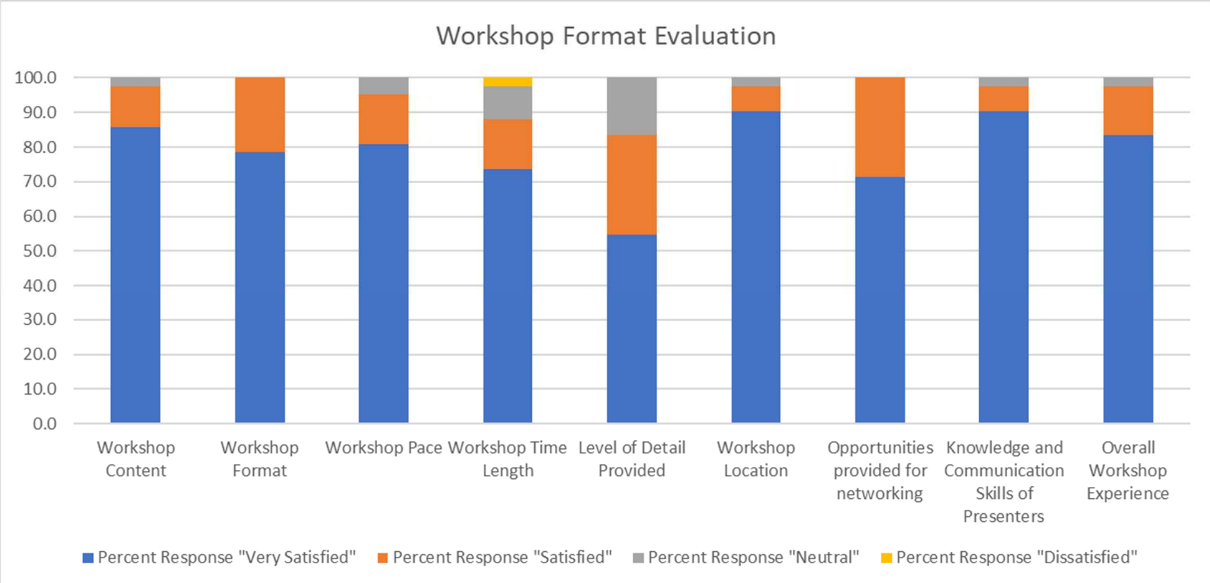

Figure 2: Evaluation of workshop content, format, pace, duration, location, opportunities for networking, knowledge and communication skills of presenters, and overall workshop experience.

The subjective and objective assessments of educator knowledge on climate and SLR at the workshops showed increases. The self-scored five-point Likert scale for the question "I can explain the difference between climate and weather" was used as a proxy for confidence in educating on climate-related topics. There was a slight positive increase in self scoring from the start of the workshop compared to scoring at the end of the workshop. The average score on the educators' pre- and post-tests (objective assessment of knowledge change) increased for both workshops. The mean Alabama score increased by 13% with pre-test scores of 55% (+/-45%) and post-test scores of 68% (+/- 28%). The mean Mississippi score increased by 8% with pre-test scores of 56% (+/- 34%) and post-test scores of 64% (+/- 31%).

Educator feedback was collected on the content of the lessons as well as the structure of the curriculum. Educators recommended that some lessons with multiple activities be adjusted to run in tandem to better fit into class timing. Strengths for each lesson were also recorded to ensure that updates maintained the most useful parts of each lesson. Overall curriculum strengths were that the lessons were hands-on, easily re-creatable in a classroom setting, used cost effective supplies, used easily understandable language, and offered critical thinking and cooperative learning components for the students. Curriculum structure updates included creating "teacher" and "student" pages, "bell ringer" and "exit ticket" questions, and adding more images to the lessons.

3.3 Pilot and Beta Testing

The educators in our classroom testing represented a range of public and private schools with 7 of the 11 schools classified as Title I schools, meaning they have a large proportion of students from low-income households. The *Sea-Level Rise in the Classroom* curriculum was pilot tested by twelve teachers in coastal Mississippi and Alabama through two Pilot-Test rounds. Educators used two of the four modules and provided feedback on ease of use, student engagement, learning objective alignment, strengths, and areas for improvement. Based on their feedback, the curriculum was updated to include corresponding PowerPoints, teacher answer keys, additional discussion questions, and virtual field trips. All twelve of the unique educators from both Pilot-Tests indicated increases in their own knowledge of SLR and resilience. They also commented that there were topics in the curriculum that were illustrative and surprising (e.g., "*While I am aware of sea level rise, I remember being shocked during the teacher workshop at the projections of how soon it will occur.")*. In semi-structured follow-up interviews, educators explicitly stated that they felt more confident in teaching the subject matter after using the curriculum. Additionally, via the post-Pilot Test digital survey instrument in response to the question of how likely they are to recommend the curriculum to a colleague, 64% of the Pilot-Test educators were considered "promoters" and 36% were considered "passive" in the Net Promoter Score. The Net Promoter Score comes from answers to survey respondents' likelihood to recommend the curriculum to a friend or colleague. It groups respondents who rate 9 or 10 as "promoter," 7 or 8 as "passive," and 6 or lower as "detractors." Nine educators participated in the Beta-Test, three new and six returning from the Pilot-Test. Sixty percent of the educators were considered "promoters" and 40% were considered "passive" in the Net Promoter Score.

In Pilot Testing and Beta Testing, knowledge increases and behavior changes were indicated in the student Pilot-Test evaluations (Module 1, n= 181; Module 2, n=61; Module 3, n=12; Module 4, n=45). In the Pilot-Test Module 1 comparisons, there were statistically significant knowledge increases regarding the connection between SLR and climate change, the causes of SLR, and SLR impacts on communities. The other three modules had small sample sizes because Pilot-Test teachers were assigned only 1 module from Modules 2, 3, and 4, and there were no significant trends in knowledge change. There was an increase in students' frequency of doing sustainable actions, with a significant shift away from students "never" doing sustainable actions (-5% change). Students also reported an increase in talking to others about SLR (6% change) and supporting environmental causes focused on climate change (4% change).

Analysis of Beta-Test student pre- and post-tests (Module 1, n=103; Module 2, n=95; Module 3, n=181; Module 4, n=124) indicated statistically significant improvement on some content areas (Fig. 3).

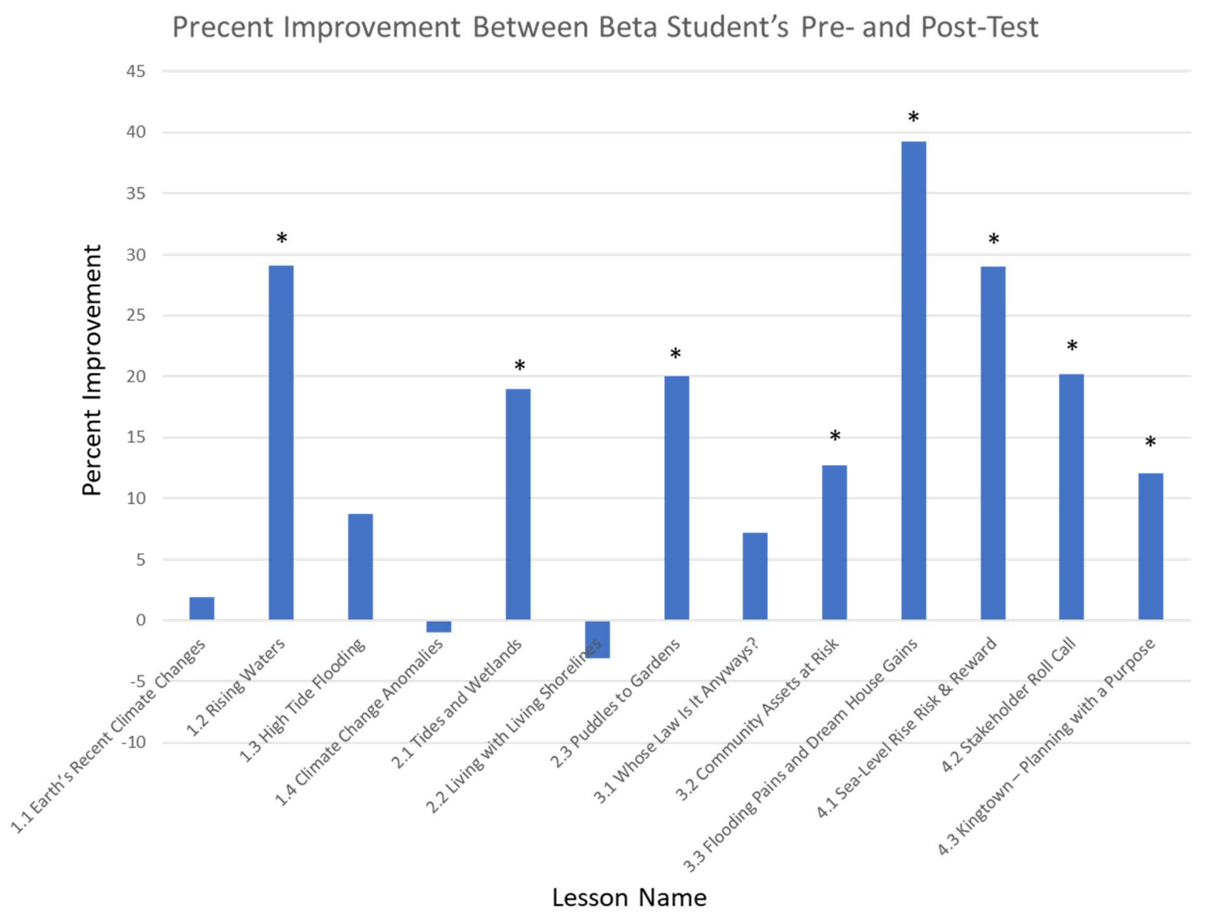

Figure 3: Percent improvement between Beta student's pre- and post-tests for content area in each lesson. Asterisks above bars indicate statistically significant changes from pre-test to post-test.

In the Hazard Summit hosted during the Beta-Test, three schools competed in Mississippi and six schools competed in Alabama. Mean student team score in Alabama was 25.5 points (+/-12.7), and in Mississippi was 25.1points (+/-6.1). The winning Alabama team scored 31.9 points and the winning Mississippi team scored 28.2 points. Winning teams thoughtfully communicated how they prioritized topics and attempted to make feasible plans. Less successful groups proposed unrealistic plans like relocating all residents and elevating every road.

Educators have continued to apply the curriculum even without fiscal support from the Project Team. Three educators who did not continue into a Beta-Test effort still used the curriculum with their students. The educators who continued to use the lessons have reached an additional 42 students as of May 2021.

4. Discussion

The developed curriculum and assessment demonstrates that SLR education can effectively be implemented in a wide range of classrooms. The lessons have been used in a range of courses from Marine Biology/Science to Local Culture to Earth and Space Science suggesting a benefit in a multitude of classrooms and subjects. A cross-section of coastal students have used the curriculum and continued curriculum use offers the opportunity to further analyze trends across diversity factors. During the Pilot-

Test and Beta-Test, teachers used the module system for a minimum of one semester, but now they have the training and supplies to continue to integrate the modules into classroom curricula to expand upon the lessons with new classes. Since the end of the project, many of these educators have continued to use the curriculum in full or partially with new groups of students, indicating they are better able to teach climate content. The Pilot-Test and Beta-Test educators are applying the curriculum in their classrooms and sharing the content with fellow educators of other courses.

Data and evaluative comments show that teacher workshops were a valued component of the project as they increased confidence and adaptation. Providing educators with training has helped them adapt the curriculum for use beyond the project term. Seventy-five percent of educators from the Pilot-Test who did not continue into the Beta-Test continued to use the curriculum with their students beyond their requirement, resulting in sustainability of the curriculum post-funding. The approach of this project was to develop the curriculum alongside educators to adjust to their feedback and ensure the final product was user-friendly. Additionally, we offered the workshop training as a safe place for educators to explore the content and ask questions to increase their comfort before teaching at the front of a classroom. After attending the workshop, educators' knowledge increased as demonstrated in the workshop pre- and post-tests, and educators indicated better understanding of climate change. Professional development with a subject-matter focus further led to successful implementation in the classroom (Garet et al., 2001). Working with these educators, we are increasing their confidence and the likelihood of peer-to-peer sharing leading to wider curriculum use. As evidenced by many of our educators in the classroom testing, they have or have planned to recommend the curriculum to their colleagues (64% of Pilot-Test, 60% of Beta-Test). Given the value the trainings added to the curriculum the Project Team has continued to develop opportunities to train educators on the curriculum. This has included a train the trainer approach wherein we co-host trainings with other educator-oriented organizations such as the Gulf National Estuarine Research Reserves and the Audubon Nature Institute. Further, Project Team members also already conduct educator workshops in which this curriculum has been integrated.

It is challenging for teachers to find SLR content that is up to date, science-based, locally relevant, and solutions driven (Plutzer et al., 2016; Turner, 2016). Our curriculum provides that with a balance of background material provided to the teacher and content material for the students. We designed lessons around models to examine SLR impacts on erosion and interaction with storm surge, how to prioritize at risk locations, and more. Our Project Team shared their career work in a way understandable by students, so that nature-based solutions, policy solutions, and community planning solutions were accessible. The project developed a method for instilling confidence in educators who teach SLR concepts through a research-based curriculum and targeted professional development.

Students and educators were directly exposed to the current science supporting SLR and flood resilience. Project Team members active in coastal and estuarine research were directly involved in the development of the science-based curriculum, providing the most up-to-date advancements in the state of knowledge as appropriate. Results from the student pre- and post-tests indicated that many areas were statistically significant in knowledge improvement. The students who participated in this curriculum demonstrated an increase of knowledge through the pre- and post-test assessments as well as the submitted capstone resilience plans. Without a control group, there are limitations in determining if these changes only came from the curriculum, however, it does suggest the curriculum changed behaviors and attitudes. Students were also exposed to solutions through a workforce development avenue, expanding knowledge of available science-based career paths. Frequently, students' perceptions of science-based careers center around traditional academic roles. Exposure to other STEM jobs, especially in underserved communities, highlights for students that there are many career choices under the broad umbrella of science. Furthermore, the curriculum demonstrates how important different roles are to application of science in daily decision-making and coastal resilience.

Robust resilience action and policy is based on scientific knowledge and founded in community values (Bozeman and Sarewitz 2011). The curriculum content is designed to bridge traditional science concepts with social studies and civics. Knowing that students better understand concepts when they are connected to multiple subjects (Belova et al. 2017), we have brought together science and social studies standards in the modules. By connecting the science concepts to civic processes, we are helping students understand the issue of SLR and necessary community action for resilience. Holistic and multi-disciplinary approaches that incorporate science education, environmental education, and social studies education are foundational for community resilience education (Bey et al., 2020). The results from the Pilot and Beta testing support this given the observed increase in content knowledge as well as through statistical significance for certain topics like thermal expansion of water and information on mitigation funding (Fig. 3). Additionally, the student capstone projects presented at the two state Hazard Summits demonstrate competence in critically thinking about the impacts and solutions of SLR. The Hazard Summit teams presented imaginative and expansive resilience solutions and expressed enthusiasm for participating in the project.

The inclusion of stories from Mississippi and Alabama towns gave the students examples of SLR impacts and solutions from their own area, as demonstrated through teacher interviews. This allowed students to feel the connection of SLR to their own lives to understand phenomena they might see, such as high tide flooding or the reason for elevated houses (Akkaş and Cevat, 2021). Highlighting locally relevant solutions increases the relevance of SLR impacts in students' lives (Moser and Dilling 2007) and empowers students to take action to protect their own community (Moser and Pike 2015). Place-based models of climate change can even help overcome political polarization and motivate people to participate in climate adaptation planning processes (Adger et al. 2013). We also strove to make connections to existing educational institutions so that teachers could connect what the students were learning in the classroom to hands-on experiences around them. Environmental education institutions are a trusted source of science information (Spitzer and Fraser 2020), and by connecting to them through this curriculum, we help broaden their programming with SLR activities and help students have hands-on instruction. Our curriculum is relevant for Mississippi and Alabama students, but the concepts of SLR impacts and community resilience are applicable for classrooms across the country, and these lessons can be used by any teacher to bring SLR into their classroom.

5. Conclusions

SLR is disproportionately affecting the northern Gulf of Mexico due to a confluence of socioeconomic challenges, higher than average rates of SLR, and low-lying topography (Fleming et al. 2018; Martinich et al., 2013; Sweet et al., 2017). In the Gulf of Mexico, 99% of the most socially vulnerable residents are projected to abandon their coastlines because these communities lack the capacity to protect themselves. To avoid such devastating impacts, at-risk communities need support that empowers residents and coastal decision-makers to take adaptive action. Educated teachers and students are less vulnerable to hazards because they can prepare and recover (Frankenberg et al. 2013; Muttarak and Lutz 2014; Sharpe et al. 2019). We worked to have equity and inclusion not only in the lessons we created but in the classrooms in which they were tested. Hazards uniquely affect different communities and it is important to address existing societal inequities (Matin, Forrester, and Ensor 2018; The Greenlining Institute 2019). Our lessons address SLR through the lens of reducing community vulnerability at the community level. Preparing our students to be informed coastal citizens is essential for them growing into resilience action-takers.

By developing a curriculum to address SLR impacts and present the multitude of solutions, we are helping equip the next generation of community planners, natural resource managers, elected officials, and coastal residents with solutions to tackle this issue. Through the development of this curriculum, the scientists on our Project Team translated their coastal processes research for students, reaching an audience that was previously unable to access this knowledge. With the connection of the science of SLR to community planning, we highlighted the importance of civic processes and lowered the societal barrier of lack of political action. We developed the curriculum incorporating educator feedback to ensure the end product presented the science in a way useful to teachers. We also provided training through educator workshops to further reduce the barriers for implementation and build confidence in the educators' understanding of the concepts. The project produced not only a detailed curriculum but also a procedure for successful development of future curricula on complex topics that are poorly understood among non-technical audiences. By using the lessons in their classrooms, educators are guiding students through the process to understand the complex nature of large-scale, long-acting problems in our communities and instill hope and the skills for the next generation to address them.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendices

Appendix A: Capstone Rubric

Appendix B: Student pre- and post-test questions

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