Development of Innovative Educational Modules to Empower High School and Undergraduate Students to Pursue Careers in Resilient Coastal Infrastructure

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Abstract

This research-to-practice full paper delineates the development and impact of an educational initiative at the University of Puerto Rico at Mayagüez, sponsored by the Coastal Resilience Center at the University of North Carolina at Chapel Hill. This initiative utilizes constructivist, experiential, and immersive learning theories to create engaging, practical learning experiences for high school and undergraduate students, specifically tailored to the unique challenges of Puerto Rico—a region frequently subjected to extreme natural events and exposed to multihazard risk. The primary objective of this educational initiative is to address the severe shortage of professionals capable of managing and aiding recovery from natural disasters in coastal and neighboring regions. Through educational modules hosted on the Interactive Learning Hub (IL-HUB), the program aims to attract talented STEM and other disciplines students, cultivate a skilled workforce, enhance infrastructure resilience, foster innovative problem-solving skills, and bridge the gap in professional expertise necessary for effective disaster response and recovery. The initiative is particularly relevant given Puerto Rico's vulnerability to hurricanes, earthquakes, and other natural hazards. By leveraging real-world scenarios and hands-on activities, students gain a deep understanding of resilient coastal infrastructure (RCI) and disaster management practices. A mixed-method, performance-focused survey approach was employed to evaluate the effectiveness of this initiative, involving quantitative pre- and post-module assessments complemented by qualitative feedback from participants. Survey responses indicate that 85% of participants rated the lectures and activities positively, expressing satisfaction with the quality of the presentations, organization, and clarity of expression. Additionally, 85.7% of students reported a heightened curiosity or commitment to pursuing further studies or careers in resilience-related fields, highlighting the significant impact of the program on student engagement and interest in RCI. These results demonstrate a significant level of student engagement and understanding of RCI, suggesting that these modules substantially promote learning and resilience planning while encouraging students to consider these areas as a professional career path. The paper outlines specific educational outcomes, including enhanced student interest in RCI careers and better preparation for addressing coastal challenges. By detailing these methods and results, the paper aims to provide a replicable model for educators seeking to integrate similar frameworks into their curriculum. This approach contributes valuable insights into the practice of engineering and resilience education in disaster-prone areas, ultimately supporting the development of a new generation of professionals equipped to handle the complexities of coastal resilience and disaster management.

Keywords— *resilient infrastructure, disaster management, experiential learning, workforce development*

I. Introduction

The geographical, social, and climatic conditions of Puerto Rico place it at a high risk for numerous natural extreme events causing critical hazards, including tropical cyclones and rainstorm events (coastal riverine, and urban floods, torrential rainfall, extreme winds, landslides), earthquakes (tsunamis, landslides, soil liquefaction), droughts, and heat waves, among others. During the past decade communities in the entire island have faced catastrophic events which have severely impacted their wellbeing. As a result, the island has experienced significant challenges in maintaining essential services and economic stability during and after such events. These events have repeatedly underscored the critical importance of resilient coastal infrastructure (RCI), essential not only for immediate response capabilities but also for the long-term recovery and stability [1] of the island. The devastating impacts of multiple hazards like Hurricanes Irma and Maria (2017), Isaias (2020), Fiona (2022) and TS Ernesto (2024), as well as the 2020 earthquake sequence have highlighted not just the vulnerability of Puerto Rico's infrastructure [2], but also the severe shortage of trained professionals capable of effectively planning, constructing, and maintaining such infrastructure.

Recognizing the need to address these challenges, the University of Puerto Rico at Mayagüez (UPRM) has partnered with the Coastal Resilience Center (CRC) at the University of North Carolina Chapel Hill to develop and implement an innovative educational initiative aimed at enhancing the workforce preparedness in resilient coastal infrastructure. This initiative leverages constructivist, experiential, and immersive learning theories, offering practical, hands-on, and engaging educational experiences to high school and undergraduate students to address the critical shortage of skilled professionals in the field of resilient coastal infrastructure, essential for managing and recovering from natural disasters. The initiative's primary objectives include cultivating a workforce adept at enhancing infrastructure

resilience, fostering innovative problem-solving abilities, and bridging existing gaps in professional expertise. By deploying educational modules, the program aims to inspire and equip students with the necessary skills and expertise to pursue careers in this area. These efforts are crucial for building effective disaster response and recovery capabilities, ensuring that communities are better prepared to resist and respond to future challenges. By integrating the robust academic resources and research capabilities of both UPRM and CRC, innovative virtual reality (VR) modules, and a comprehensive e-learning environment, this initiative ensures a multifaceted educational approach. This integration enables the dissemination of cutting-edge research and interactive educational content to a broader audience, enhancing both the reach and the impact of this resilience training program.

II. The UPRM Coastal Resilience Center Initiative

The CRC, led by the University of North Carolina at Chapel Hill and in partnership with multiple institutions including the University of Puerto Rico at Mayagüez (UPRM), is part of the strategic national response to coastal hazards. Funded by the Department of Homeland Security, the CRC's goal is to provide a comprehensive approach to enhancing the resilience of communities, infrastructures, economies, and natural environments against the impacts of coastal hazards [3]. The center's research and education capabilities span coastal flood, storm surge, and extreme hurricane wind; hazard mitigation and recovery planning; and education and training of the current and future homeland security enterprise workforce.

The Civil Engineering and Surveying Department at UPRM has integrated a robust educational initiative through the UPRM Coastal Resilience Center (UPRM-CRC) that emphasizes resilience in coastal infrastructure, particularly in the face of Puerto Rico's vulnerability to natural disasters. This initiative has had a significant impact, with more than 50 high school and 600 university students participating every year through various platforms, such as the Pre-Engineering Summer Camp, the Summer Transportation Institute (STI) Camp, and other high school students who participate in university orientations. The Pre-Engineering and STI Summer Camps at UPRM focus on orientations and workshops as recurring modules, forming an integral part of the broader educational outreach aimed at enhancing understanding and skills in multi-hazard resilience. These camps are designed to engage high school students, providing them with foundational knowledge and hands-on experiences in civil engineering and infrastructure resilience.

The backbone of this initiative is a learning management system hosted on Moodle, known as the Interactive Learning Hub (IL-HUB). The IL-HUB serves as a repository for the delivery of educational modules, workshops, and seminars that prepare students and professionals to tackle the multifaceted challenges posed by disasters caused by extreme natural events[4]. This platform ensures that learning transcends traditional classroom boundaries, reaching a wider audience with crucial knowledge on disaster preparedness and response. Interactive video-based learning using H5P is a type of student response system (SRS) used to enhance engagement and interaction in educational settings [5], allowing real-time feedback from students. Interactive videos like those created with H5P incorporate quizzes, prompts, and reflection points directly into the video content. This not only maintains student engagement but also allows for immediate assessment and feedback. These interactive elements can transform passive video watching into an active learning experience where students respond to questions, make decisions, and reflect on the material as they progress through the video. This method is particularly effective in ensuring that students not only consume content but also actively process and understand it.

The educational modules provide students with a comprehensive understanding of natural phenomena, applying engineering methodologies and advanced technologies to assess and mitigate risks faced by infrastructure and communities. It explores state-of-the-art resilient and sustainable alternatives to address community risks (hazard-exposure-vulnerability) effectively. Additionally, it creates robust pathways for students and professionals into careers in RCI. A graphical representation of the resilience cycle, which students are introduced to, is presented in Fig. 1, depicts the complexity of assessing, addressing, and achieving resilience for enhancing the state of security of exposed and vulnerable communities at risk. It also highlights the importance of the continuous educational process to achieve a new state of capacity building and supply the necessary workforce for the national homeland security enterprise.

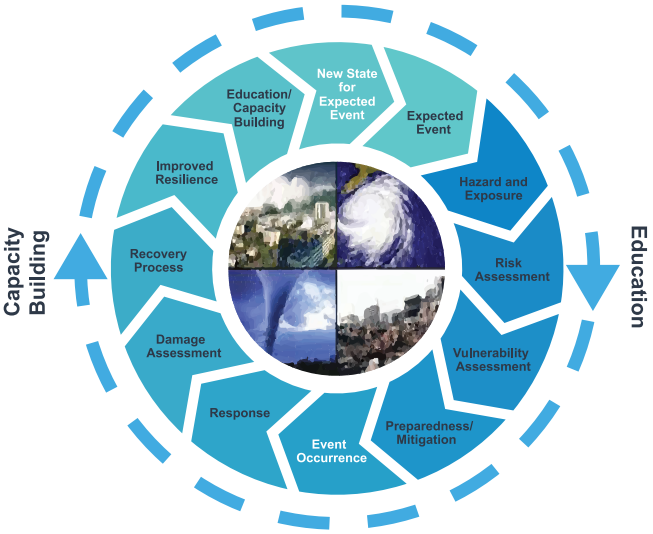

Fig. 1: Conceptual resilience cycle diagram

Additionally, the department offers the course Contemporary Topics in Civil Engineering (INCI 3000), which has been a primary vehicle for delivering modules to freshman, sophomore, and junior students. This course is part of a broader curriculum that includes specialized project-based learning experiences in courses such as Water Resources Engineering (INCI 4138), Civil Engineering Comprehensive Design Capstone (INCI 4950), and the Civil Engineering Seminar (INCI 4019), which require students to assess, analyze, and design comprehensive civil engineering design projects of resilient and sustainable urban infrastructure.

III. Project Approach

The research design for this project incorporates three core elements: constructivist, experiential, and immersive learning strategies, each contributing to a comprehensive and integrated educational framework to enhance student experience (See Fig. 2). The principles of constructivist learning encourage students to build or *construct* knowledge based on their existing understanding and experiences [6]. In Puerto Rico, students can incorporate a unique perspective to learning, having personally experienced the realities of natural disasters. This firsthand knowledge, which transcends what can be taught through textbooks or traditional courses, enriches their educational experience, and deepens their understanding of the

complexities involved in disaster management and resilience. The educational initiative begins with a comprehensive orientation session, where students are introduced to the resilience module, outlining the objectives, and expected competencies to be developed throughout the workshop.

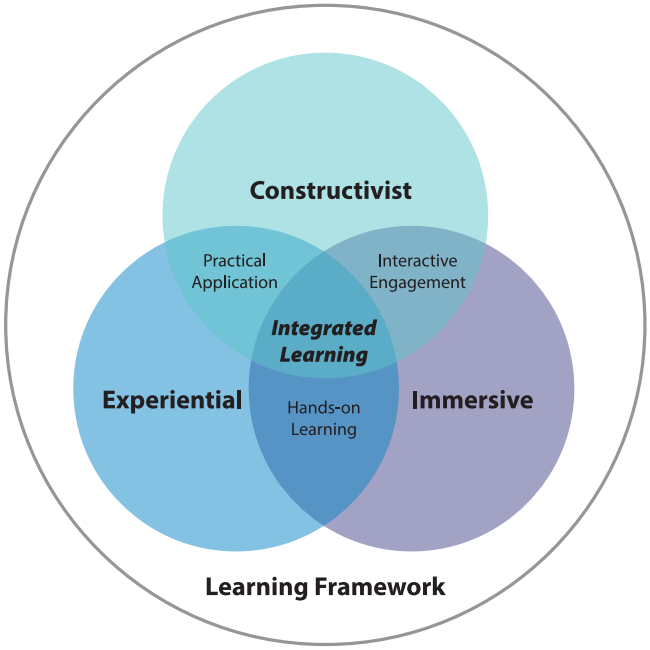

Fig. 2. Diagram illustrating the proposed integrated learning framework, where constructivist, experiential, and immersive strategies converge to enhance educational effectiveness and engagement through integrated learning

This session sets the stage for deeper engagement by fostering dialogue on students' personal experiences with natural disasters, utilizing these discussions as a constructivist approach to build on their prior knowledge. This prepares students for the experiential learning experience ahead. Following the introduction, a detailed presentation on the resilience cycle—comprising phenomenology, risk, preparation, response, recovery, and mitigation—is delivered. This presentation leverages visual aids, interactive content, and guest speakers to enrich the learning experience and provide students with a robust understanding of the concepts. Through this approach, students actively connect their personal experiences to the theoretical frameworks presented, enhancing their overall comprehension and engagement. The experiential, or active, learning is integrated through hands-on activities that allow students to apply concepts in practical settings, enhancing their learning experience. For this strategy, students engage in practical application exercises using available tools (e.g., NOAA's flood inundation mapping, which allows students to apply theoretical knowledge to real-world sea-level rise and flood scenarios (https://coast.noaa.gov/floodexposure).

For the immersive strategy, an immersive virtual reality (VR) module is introduced, transforming the learning environment into a simulated news studio (Fig. 3). In this VR setting, students find themselves moving around, interacting with several monitors, each displaying videos that cover various topics within the resilience cycle, including different types of natural hazards and appropriate disaster response strategies. This immersive learning experience allows students to engage with and explore detailed content on how to effectively mitigate and respond to disasters.

Fig. 3. Screen capture of the VR module

This educational initiative exemplifies the power of *integrated learning* by seamlessly combining practical application, interactive engagement, and hands-on learning to create a dynamic educational experience. Through the practical application of constructivist principles, students build on their unique, firsthand experiences of natural disasters, transforming theoretical knowledge into personal insight and deeper cognitive connections. Interactive engagement is fostered in both the orientation sessions and the VR environment, where students actively discuss and analyze their experiences and the presented content, further enriching their learning process. The hands-on learning strategy immerses students in practical scenarios using tools for inundation mapping, allowing them to apply their knowledge in realistic settings that mirror the challenges they will face in professional contexts. Collectively, these strategies not only bolster students' understanding and skills but also prepare them to effectively contribute to disaster management and resilience planning. As such, this approach does not merely educate; it empowers students to become proactive participants in building resilient communities, showcasing the transformative potential of integrating multiple educational methodologies.

IV. Project Assessment

In recent years, the emphasis on measuring and enhancing the effectiveness of educational programs has significantly increased. However, traditional learner surveys often rely on Likert-like scales, which, while popular, are unable to provide clear distinctions between answer choices, potentially leading to biased responses and cognitive fatigue. This traditional approach can obscure the real impact of learning interventions, leading to less actionable feedback. In response, performance-focused learner surveys, as advocated by Will Thalheimer [7], represent a shift towards more effective evaluative techniques. These surveys aim to move beyond mere satisfaction or basic understanding to measure how training translates into actionable skills and behaviors in the workplace or field-specific settings.

Thalheimer's model is particularly concerned with supporting learning design effectiveness, aiding learners in the application of their knowledge, and nudging them towards continued learning and application efforts.

Thalheimer's approach to learner surveys incorporates distinctive questioning that targets various levels of learning effectiveness—from understanding and remembering to applying and impacting. This method aligns with modern educational needs by emphasizing the importance of real-world application and ongoing engagement with learned material. For the field of resilient coastal infrastructure, where the application of learned knowledge to practical scenarios is crucial, employing such advanced survey techniques can significantly enhance the quality of educational outcomes. By leveraging performance-focused surveys, educational programs can effectively gauge the transfer of knowledge into practice, enabling continuous improvement in curriculum design and delivery. This approach not only assesses the immediate learning outcomes but also provides insights into the long-term retention and application of knowledge, essential for addressing the complex challenges of coastal resilience education and maintaining student motivation.

V. Results and Discussion

The pre-engineering summer camp was designed to introduce students to various aspects of engineering and resilience, aiming to spark their interest and provide a foundation for further exploration in these fields. Through a combination of lectures, activities, and discussions, the camp sought to engage students, enhance their understanding of engineering concepts, and encourage them to consider future studies or careers in related areas. This section presents an analysis of the students' feedback, focusing on their overall experience, the effectiveness of the orientation, and the impact the workshop had on their interest in resilience as a potential career path, based on the performance-focused theory. The findings highlight both the strengths of the program and areas where improvements could further elevate the student experience. The analysis of the data from the pre-engineering summer camp reveals that students generally had a favorable experience, with a significant majority providing positive feedback across various aspects of the orientation. Figure 4 evaluates specific elements of the orientation.

It shows that 85% of students rated the quality of the presentation as either "Excellent," "Outstanding," or "Acceptable" (35%, 30%, and 20%, respectively). Only 15% of students felt the presentation was "Regular" or "Deficient," indicating that while there is some room for improvement, the presentation was largely well-received. Similarly, the organization and sequence of the orientation were rated positively by 85% of students (35% "Excellent," 30% "Outstanding," and 20% "Acceptable"). This trend of strong positive feedback continued for clarity of expression, where 85% rated it positively (30% "Excellent," 35% "Outstanding," and 20% "Acceptable"), though 15% still felt it was less than ideal. These less favorable opinions may reflect students lack of personal interest for the field.

When evaluating the presenters' mastery of the topic, 85% of students rated it as "Excellent," "Outstanding," or "Acceptable" (35%, 30%, and 20%, respectively). This indicates that the presenters were generally seen as knowledgeable, though a small percentage (15%) felt there was room for improvement. The organization of the activity also garnered 85% positive ratings, with 35% rating it as "Excellent," 30% as "Outstanding," and 20% as "Acceptable." Time management, while still positively rated by 80% of students (30% "Excellent," 30% "Outstanding," and 20% "Acceptable"), saw slightly lower ratings, with 20% of students feeling it was "Regular" or "Deficient." The relevance of the content was perceived positively by 85% of students (35% "Excellent," 30% "Outstanding," and 20% "Acceptable"), though 15% rated it lower. The session of questions and answers and the resources used during the orientation also received high ratings, with 80% of students rating these aspects as "Excellent," "Outstanding," or "Acceptable." However, 20% rated them as "Regular" or "Deficient," indicating a need for slight adjustments. The overall reaction to the activity was similar, with 80% of students expressing a positive reaction, but 20% feeling less satisfied.

The qualitative feedback provided by the students supports this positive assessment, with many expressing appreciation for learning about coastal risks, especially those living near the coast. This aligns with the 85% who rated the relevance of the content positively. Several students also found the presentation informative and well-organized, mirroring the majority who rated the quality, organization, and clarity of the presentation favorably. However, some students offered suggestions for improvement. The feedback highlighted that the presentation could be more engaging, which corresponds with the 20% who rated time management as "Regular" or "Deficient."

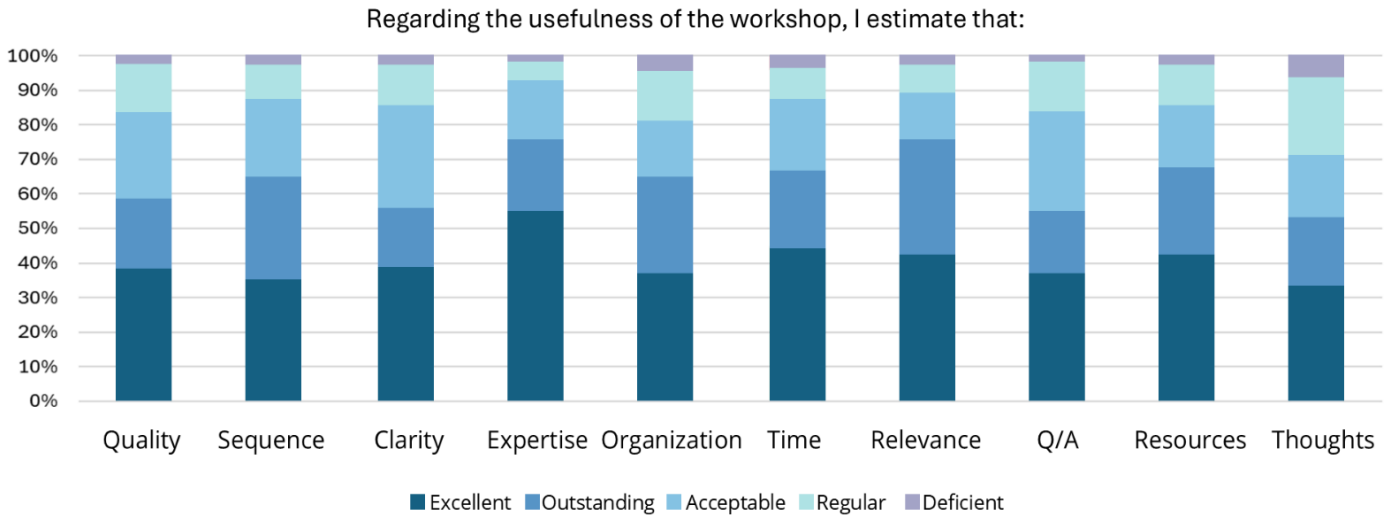

Fig. 4. Data collected for the Educational Module

Additionally, some students had difficulty seeing the connection between the topic and engineering, suggesting a need for better integration of engineering concepts. This concern is reflected in the 20% who rated their overall reaction as "Regular" or "Deficient." A small minority of students expressed dissatisfaction, describing the session as irrelevant to their interests. This aligns with the 20% who rated their overall reaction to the activity as less than positive. Despite this, many students—80% to 90%—provided favorable ratings, indicating that while the orientation was generally well-received, there is potential to enhance engagement and relevance further.

Data regarding the impact of the workshop on students' decisions to pursue studies or careers in the field of resilience was collected (Fig. 5). When considering "acceptable" responses—options b, c, d, and e—a substantial 85.7% of students indicated that the workshop had a positive influence on their interest in resilience-related fields. Specifically, 33.3% of students found the workshop intriguing enough to consider exploring courses or formal roles in resilience, while 23.8% felt that the workshop piqued their curiosity, though they need more information before fully committing to this area. Furthermore, 19% of students stated that the workshop reinforced their decision to specialize in resilience professions, and 9.5% expressed that they are already very interested and plan to seek further education and opportunities in this field.

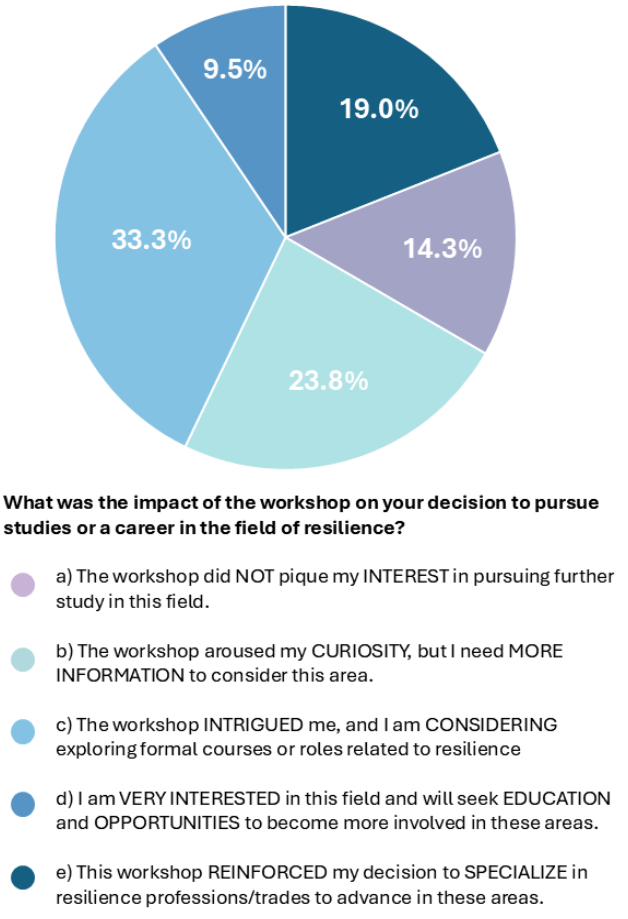

Fig. 5. Module impact on student engagement and interest on pursuing education in resilience-related disciplines

These results are promising, as they demonstrate that the workshop successfully sparked or reinforced interest in resilience for many participants. However, the 23.8% of students who selected option b—indicating curiosity but requiring more information—highlight an opportunity for improvement. To fully engage these students and potentially convert their curiosity into a committed interest, future iterations of the workshop should include additional support, such as follow-up information sessions, mentoring opportunities, or more detailed presentations on the practical applications and career paths in resilience. By addressing the needs of these students, the workshop can further increase its effectiveness in guiding students toward careers in this vital field.

In summary, the data suggests that the summer camp orientation was largely successful, with a significant majority of students providing positive feedback across various metrics. The workshop not only intrigued many students but also positively influenced their interest in resilience-related fields, with 85.7% indicating a heightened curiosity or commitment to exploring further education and careers in this area. To build on this success, future orientations could benefit from incorporating more interactive elements, clearly connecting the content to engineering topics, and perhaps shortening or restructuring the sessions to maintain engagement. Additionally, providing more support and information to the 23.8% of students who expressed curiosity but are not yet fully committed could further enhance the program's impact. These changes would help address the concerns of the 20% of students who felt certain aspects of the orientation could be improved, thereby boosting the overall effectiveness and satisfaction of the program.

VI. Conclusions

The UPRM-CRC initiative has successfully applied innovative educational techniques to enhance the learning experience for high school and undergraduate students, providing them with a comprehensive understanding of coastal resiliency topics. The initiative has not only bolstered the educational offerings at UPRM in a recently approved curriculum but has also been pivotal in preparing students for careers in disaster management and resilience planning. Feedback from participants indicates a high level of satisfaction with the structure and content of the modules, particularly the opportunities to engage with advanced simulation tools that closely mimic professional engineering tasks. These hands-on experiences are invaluable, equipping students with the practical skills and knowledge necessary to tackle the multifaceted challenges of building and maintaining resilient infrastructures in disaster-prone areas.

The integration of constructivist, experiential, and immersive learning strategies within the UPRM-CRC initiative has proven to be a comprehensive and effective framework. By leveraging constructivist principles, students were encouraged to build on their unique, firsthand experiences of natural disasters, deepening their understanding and connection to the subject matter. The experiential learning elements allowed students to actively apply theoretical knowledge in real-world scenarios, such as using NOAA's flood inundation mapping tools, reinforcing their learning through practical engagement. Additionally, the immersive learning strategy, particularly through virtual reality (VR), provided a dynamic and interactive environment that further enriched the students' learning experiences.

The results from the program are promising, with 85% of participants providing positive feedback and 85.7% expressing a heightened interest or commitment to pursuing careers in resilience-related fields. These outcomes highlight the effectiveness of the CRC

initiative in bridging the gap between theoretical learning and practical application, making a significant contribution to the field of engineering education. The program not only educated students but also empowered them to become proactive participants in building resilient communities.

While the educational module was largely successful in meeting its objectives, continuous refinement of the program will be essential to maximizing its impact. Addressing the areas identified for improvement, particularly providing more information and engagement opportunities for students who are curious but not yet fully committed, will be crucial. By doing so, the initiative can more effectively inspire and prepare students for future careers in engineering and resilience, contributing to the development of the next generation of professionals in these fields. Overall, the positive outcomes observed from this initiative underscore its significance in preparing students to handle the complexities of coastal resilience and disaster management.

VII. Acknowledgment

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