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ASSESSING INTERDISCIPLINARITY IN A COLLABORATIVE UNDERGRADUATE STEM PROGRAM IN RESILIENT AND SUSTAINABLE INFRASTRUCTURE

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The academic preparation of scholars on infrastructure-related disciplines often takes place within isolated professional domains, rarely embracing an interdisciplinary approach for problem solving. The current work describes the implementation and outcomes from an undergraduate program designed to increase students' awareness and knowledge of infrastructure vulnerabilities to students pursuing engineering and architecture degrees. The program, titled "Resilient Infrastructure and Sustainability Education -Undergraduate Program" utilizes the devastation from Hurricanes Irma and María for implementing an interdisciplinary case study methodology to understand and generate solutions to a variety of complex infrastructure challenges in a real-life setting. Project Based Learning (PBL) constitutes the theoretical model that frames this study. The sample included 23 undergraduate students, from architecture and engineering, and from three different campuses. All students completed a course sequence of 15 credits in design and construction of resilient and sustainable infrastructure. The results indicate that the program outcomes were achieved: development of interdisciplinary research skills and project design, hands-on solutions for real problems, awareness of human factors on project design, understanding of the importance and contribution of different disciplines and perspectives, and most important, developing the interest of putting into practice learned knowledge and skills in future projects. Students internalized the value of sustainability and resilience, in their coursework and future professionals, but also personally, applying these principles in their daily life. Students reported that their initial expectations about the program were either achieved or exceeded what they had foreseen. They considered a strength having three campuses and several disciplines working collaboratively.

Keywords: Evaluation, Sustainability, Professional development, Project-based learning.

1 INTRODUCTION

In September 2017, Hurricane María hit the island of Puerto Rico destroying its power grid, all communication infrastructure, many houses, and buildings. This event was followed by a 6.4 earthquake in January 2020 that demolished schools and other structures on the southwest of the

island. The experience from hurricane María inspired a group of professors from the University of Puerto Rico to develop a curriculum focused on design and construction of resilient and sustainable infrastructure. As a result, the project titled *Resilient Infrastructure and Sustainability Education – Undergraduate Program (RISE-UP)* emerged to educate future environmental designers and engineers, capable of providing interdisciplinary solutions to complex infrastructure problems.

It is a well-known challenge that "current university systems remain clustered around individual disciplines, and mono-disciplinary remains the modus operandi in day-to-day academic practice" (Nyamapfene 2020). Taking this into consideration, a collaborative program was created to include faculty from three programs, located in different campuses of the University of Puerto Rico: UPR-Río Piedras, which houses the School of Architecture; UPR-Mayaguez, the College of Engineering; and UPR-Ponce, who offers two-year associate and articulated degrees in Engineering and Construction. Because of their geographical location, courses are taught online, integrating in-person activities during team meetings, site visits, and field trips. This arrangement allows faculty and students from environmental design, civil engineering, electrical engineering, and surveying, with the opportunity of sharing a common curriculum and taking classes together.

The RISE-UP curriculum features interdisciplinarity instruction, case study research, the development of a case-study repository, and shared problem solving. Grounding case study research on damage produced by Hurricane María, and later by earthquakes, provides a real-life scenario to generate evidence-based solutions and make the most from students' insights after witnessing the impact of these natural disasters.

The current work presents the assessment results obtained from the first cohort of participating students. Results support the impact of the RISE-UP curriculum on students' development of interdisciplinary skills for problem solving, research, and project design.

2 RISE-UP AND INTERDISCIPLINARITY

Research in interdisciplinary engineering instruction (IEE) often cite the lack of support and facilities as institutional constraints to IEE; UPR is not the exception. Aware of this reality, RISE-UP constitutes an official minor degree that includes many elements of IEE and focuses on eliminating mono-disciplinarity among infrastructure related disciplines and professional domains.

Van den Beemt *et al.* (2020), in their review of the literature, identifies a group of themes across IEE studies: the way students are arranged and their participation, pedagogies, scaffolding, and assessment methods. These elements of interdisciplinarity are represented in RISE-UP as follows:

- Student participation and group composition - This element refers to combining different students from different disciplines to work collaboratively in solving problems. In RISE-UP, undergraduate students from different programs, campuses, and different academic levels take classes together and are grouped in working teams.
- Pedagogies - Problem-based learning (PBL) is utilized in all the RISE-UP courses in addition to a case study methodology and team teaching by professors from diverse disciplines. Students also learn how to use different software, how to complete assessments of damages caused by natural events, and other in-vivo activities.
- Scaffolding - The curriculum sequence is designed to provide scaffolding to students' knowledge across and within courses. To progress in the program, courses must be approved in an established sequence that is tied to the principles of Depth of Knowledge (Webb 1997). Accordingly, courses increase in depth and scope: the first course focuses on the fundamentals of design, resilience and sustainability and later courses stress planning, applying learned concepts and skills, and problem solving to real world cases.

Within courses, constant feedback to students is provided by faculty and experts from diverse disciplines. Each semester, students work on assignments and projects that increase in complexity, culminating in a comprehensive design project for the capstone course.

- Assessment - Rubrics, reflections, continuous feedback from faculty and experts from diverse disciplines, and peer assessment are used to evaluate projects and assignments.

3 ASSESSMENT METHODOLOGY

An evaluation of the project was performed by the first cohort of RISE-UP students that completed the 15-credit curricular sequence. The evaluation consisted of an online questionnaire assessing the gains and benefits from completing the capstone course titled *Design-Build Project Delivery (INCI 5036)* and a final evaluation of their experience throughout RISE-UP.

During INCI 5036 students were required to design a community / unit system of 4 emergency housing units to refugee people on a temporary basis but with the possibility of future expansion as permanent units. The context for this project was a real site in Puerto Rico, and human factors needed to be taken into consideration in the design. The finalized project was uploaded to the case study repository.

Twenty-three students answered the questionnaire: 26% (n=6) were females and 74% (n=17) males. This sample includes 85% of the first cohort of participants (N=27).

4 FINDINGS

The evaluation of RISE-UP consists of a mixed-method design, therefore quantitative and qualitative results are reported.

4.1 Quantitative Results

Quantitative results consist of descriptive statistics for the following: evaluation of INCI 5036 course dynamics and perceived outcomes, evaluation of RISE-UP components, evaluation of the use of case studies and repositories, and students' perceived impact of the program.

4.1.1 *INCI 5036 course dynamics*

Results ranged from 4.32 – 4.68 / 5-point scale where 1=Never; 2=Rarely; 3=Sometimes; 4=Frequently; and 5=Always. All mean values were above 4.40 which shows that course dynamics were positive and productive. Professor-student communication was also very good, the highest scores were related to opportunities for receiving feedback and guidance from professors as well as constructive feedback during the final project. Results are described in Table 1.

Table 1. Students' ratings for course dynamics.

Item	Min	Max	SD	$\overline{X}$
Opportunities for receiving feedback and guidance from professors.	3.0	5.0	0.57	4.68
Professors answered students' questions satisfactorily.	4.0	5.0	0.50	4.53
Groups worked together satisfactorily.	3.0	5.0	0.75	4.42
Each group member assumed his/her assigned task.	3.0	5.0	0.59	4.58
Communication among group members was effective.	3.0	5.0	0.73	4.32
Members valued and respected each other's opinions.	3.0	5.0	0.59	4.58
Students received constructive feedback from RISE-UP professors during the final project.	4.0	5.0	0.46	4.68

4.1.2 *Students' assessment of INCI 5036*

Mean values ranged from 4.50 – 4.80 / 5-point scale where 1=Worthless; 2= Slightly worthless; 3= Slightly useful; 4=Useful; and 5=Very useful. Mean values demonstrate that the expected outcomes for this course were achieved. The highest scores were related to being creative, considering resilience, sustainability, and human factors in designing and construction, and having an interdisciplinary approach for design and problem solving (See Table 2).

Table 2. Students' assessment of course outcomes.

Item	Min	Max	SD	$\overline{X}$
Ability to work collaboratively with students from different disciplines in designing a project.	3.0	5.0	0.54	4.75
Being able to apply concepts, theories, and applications learned in previous RISE-UP courses.	4.0	5.0	0.43	4.75
Complete tasks requiring multiple roles, collaboration, and coordination with others.	4.0	5.0	0.43	4.75
Being able to utilize information from several sources and disciplines to fulfill a task.	4.0	5.0	0.43	4.75
Being creative when designing solutions for specific problems.	4.0	5.0	0.40	4.80
Integrating human factors in design processes.	4.0	5.0	0.40	4.80
Having assurances of resiliency and sustainability in designing and construction.	4.0	5.0	0.43	4.80
Adopting an interdisciplinary approach for design and problem solving.	4.0	5.0	0.40	4.80
Performing simulations to test airflow, a power grid, power distribution, structure resistance to hurricanes and earthquakes, etc.	3.0	5.0	0.67	4.50
Ability to conceptualize a construction budget.	4.0	5.0	0.48	4.65

4.1.3 *Assessment of RISE-UP components*

Students were asked to rate how valuable they considered different components of the RISE-UP curriculum sequence and their contribution regarding their personal and academic development.

Mean values ranged from 4.61 – 4.87 / 5-point scale, where 1=Not at all valuable; 2=Not so valuable; 3=Somewhat valuable; 4=Very valuable; and 5=Extremely valuable. All mean values were above 4.60 demonstrating that all the RISE-UP components were considered outstandingly valuable, particularly the assigned projects and exercises, working in groups, stressing collaboration, and receiving feedback and critiques from professors and experts. The interdisciplinary approach was considered especially valuable, as well as employing a human design approach (See Table 3).

Table 3. Students' assessment of RISE-UP components.

Item	Min	Max	SD	$\overline{X}$
Site visits	4.0	5.0	0.44	4.74
Assigned projects, exercises, and simulations	3.0	5.0	0.57	4.61
Collaborative work among students from three different campuses	4.0	5.0	0.41	4.78
Merging architecture and engineering in conceptualization and project design	4.0	5.0	0.38	4.83
Critiques from professors and experts	4.0	5.0	0.34	4.87
Having a human design approach in courses	4.0	5.0	0.41	4.78
Having an interdisciplinary approach throughout the curricular sequence	3.0	5.0	0.53	4.74

4.1.4 *Evaluation of case studies and repository*

Questions were included to explore the usefulness of uploading and sharing case studies in the repositories for enhancing learning and development of research skills. The scale used to rate each item consisted of 1=Worthless; 2=Slightly worthless; 3=Slightly useful; 4=Useful; and 5=Very

useful. All mean values obtained were above 4.50 suggesting that sharing case studies and projects was very helpful for decision-making during the design process and for problem solving, also to understand further problems produced by disasters, and for doing research and case comparisons (See Table 4).

Table 4. Students' evaluation of case repositories.

Item	Min	Max	SD	$\overline{X}$
Visualize and summarize your ideas	2.0	5.0	0.79	4.57
Examine and compare cases	3.0	5.0	0.56	4.67
Do research and reach conclusions	3.0	5.0	0.56	4.67
Look in depth at problems caused by disasters	4.0	5.0	0.39	4.81
Making informed design decisions	4.0	5.0	0.35	4.86
Apply concepts learned	3.0	5.0	0.56	4.67
Analyze and apply information to solving given situations	3.0	5.0	0.53	4.76

4.1.5 *Impact of RISE-UP*

To assess the impact of the RISE-UP curricular sequence, students were asked if they would apply learned knowledge and skills in resilience and sustainability in their future design and construction of structures. A 5-point scale that ranged from "None at all" – "A great deal" was used.

Ninety-five percent (95%) of the students foresee applying learned skills and knowledge in resilience and sustainability in their design and construction of structures.

4.2 Qualitative Results

Qualitative results include a thematic content analysis for one of the open-ended questions included in the questionnaire. Students were asked the following: "We would like to know what you can point out as particular or unique in RISE-UP courses, that is, topics, ideas, approaches, experiences, attitudes, world views, etc. that otherwise you would have not experienced in your other engineering or architecture courses.". Eleven students answered this question.

The coding system employed consisted of identifying the frequency of topics in the text, followed by clustering topics into categories. MAXQDA 2020 (VERBI Software 2019) was employed to codify the text and generate categories as recommended by Oliveira *et al.* (2016). Thirty-five unique phrases were identified, coded, and clustered into 11 categories (See Table 5).

Table 5. Frequencies of categories identified in thematic content analysis.

Category	Frequency	Descriptor
Real-world experiences	8	Highlight site visits, hands-on projects, application of learned concepts and information
Interdisciplinary approach	7	Reference to interdisciplinarity
Course content	5	Focus on topics, coursework in courses, and learned software
Sustainability and resilience	4	Reference to sustainability or sustainability
Pedagogy	3	Focus on the teaching process
Professors	2	Highlight positive qualities of professors
Human centered design	2	Highlight having a human centered approach in design
Research experiences and skills	2	Focus on the research experience and development of research skills
Professional development	1	Reference to experiences that promote professional development
Personal growth	1	Change in attitude

The categories with the highest frequency support the obtained quantitative results, highlighting elements of real-world activities and interdisciplinarity, as well as the value of course content.

5 CONCLUSIONS

Results obtained from the assessment performed by the first cohort of RISE-UP students demonstrate that the project is very successful in developing interdisciplinary skills for research and project design, as well as awareness of the importance of resilience, sustainability, and human factors. Both quantitative and qualitative results evidence different elements of interdisciplinarity. Students identify PBL and case studies as unique pedagogies present in RISE-UP and seldom found in other courses, as well as the arrangement of working together with students from different disciplines and campuses. Support from professors and other experts, along with constructive feedback from peers and faculty is recognized as a strength of the program. The goal of developing interdisciplinary thinking is evidenced in students' conceptualization of a comprehensive final project that required applying learned skills and knowledge.

Students internalized the value of sustainability and resilience in their coursework and as future professionals; it also extended into their daily lives. Testimony of this unintended outcome is represented in the following comment: "Learning the principles of sustainability was also a big change because it affects your life as well. I find myself making more educated decisions about what to buy, what to eat, how to go about my day with a sustainability point of view.".

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