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A Collaborative Architectural/Structural Engineering Design Project: Perspectives from the Engineering Students in a Co-Taught Graduate Engineering Course

Miss Isha Galaz Abdullah, University of North Carolina at Charlotte

Isha Abdullah is a PhD candidate from the University of North Carolina at Charlotte. Her research interests include geometric stability of structures, the finite element modeling of structures subjected to extreme loading, and engineering education.

Dr. David K Pugalee, University of North Carolina at Charlotte

Dr. David Pugalee is a full professor and Director of the Center for Science, Technology, Engineering, and Mathematics Education (STEM) at UNC Charlotte. Dr. Pugalee has published works on STEM teaching and learning and on the NSF project Developing a Systemic, Scalable Model to Broaden Participation in Middle School Computer Science that focuses on computational thinking in science and mathematics. He has more than twp decades of classroom teaching experience at both the K-12, including mathematics and science, and higher education levels and has led multi-million dollar grants related to STEM education.

Dr. David C. Weggel, University of North Carolina at Charlotte

Dr. David C. Weggel is a full professor and founder and director of the Infrastructure Security and Emergency Responder Research and Training (ISERRT) Facilities at UNC Charlotte. His research interests are in physical security (structures subjected to blast, impact, and ballistics), robustness and geometric stability of structures, and engineering education. He is a proponent of cross-college collaboration and project-based learning (open-ended projects) for specific courses designed to push students beyond their present way of thinking, foster creativity, and prepare them for collaborative careers.

David Jacob Thaddeus, University of North Carolina at Charlotte

David Thaddeus is Professor or Structures and Architectural Design at the School of Architecture at the University of North Carolina at Charlotte. His pedagogy is centered around teaching science based concepts to visual learners. Research interests revolve around sustainable practices in architectural design and structural analysis

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Abstract

This research focuses on the experiences of graduate-level civil engineering students from a co-taught class who partnered with undergraduate architecture students in a collaborative design project. The graduate-level *Structural Systems* course was co-taught by a structural engineering professor and an architecture professor. They provided insight into the perspectives and methodologies of the two disciplines. Five graduate structural engineering students were in the course. The architecture professor was contemporaneously teaching a third-year undergraduate architecture studio. The architecture students spent the semester designing a Social Creative Resource Center (SCRC) and were in the final design phase during the last six weeks of the semester. It was at this stage that each engineering student was paired with an assigned architecture student to participate in an interdisciplinary collaborative project-based learning experience. The engineering student served as a consultant to the architecture student, helping to resolve structural aspects of the design, while being mindful of their partner's architectural vision. The engineering students had to justify their recommendations to the architecture students and to the final architecture studio review panel.

The engineering students were required to fill out surveys and write a report detailing their recommendations, reasoning, and any resulting changes their partner made to the SCRC. A qualitative thematic analysis was conducted on these surveys and reports to explore how the engineering students characterized their engagement with the project. Co-teaching surveys were given to the co-instructors. Qualitative and quantitative analyses provided insights into their co-teaching experiences. This report discusses the themes relevant to the *Structural Systems* course. The research questions were:

1. How did the engineering students describe their experiences advising their partner?
2. What are the characteristics of the engineering students' final written project reports?
3. How did the instructors describe aspects of their co-teaching?

The analysis of the student surveys revealed five themes: Student Needs and Knowledge Gained; Communication and Empathy; Recommendations from Engineering Students to Partner; Perspectives on Project Rubric; Professor Guidance. The first three of these themes were also identified in the students' reports. The co-teaching survey highlighted the instructors' perspectives on effective co-teaching elements: classroom applications, relationships, communication, planning and knowledge base for co-teaching. Relationships were identified as vital. The thematic study exposed the benefits of the non-traditional format of this graduate course from the perspectives of the co-instructors and the engineering students. It also provided guidance for improving future iterations of this course offering; such suggestions will be presented. A future study obtaining perspectives from the architecture students is necessary.

Introduction

STEM education promotes a focus on meaningful integration of concepts across subjects [1], to encourage creative approaches to solving problems and issues. The National Academy of Sciences, Engineering, and Medicine's publication *Graduate STEM Education for the 21st Century* [2] advocates for changes in graduate STEM education to address complex multidimensional and multidisciplinary problems requiring multiple levels of analysis. Such an approach requires students to work collaboratively as they sometimes approach problems in different ways as they produce knowledge. These outcome-based problems focus on real-world applications related to metacognitive thinking which involves planning, monitoring and evaluation [3]. In this research study, the problem-based context was the learning model which has been shown to result in significant knowledge acquisition and positive learner perceptions of their cognitive and personal competencies [4]. The task required students to collaborate to reach a consensus on the best approaches, integrating key concepts in both architectural and engineering factors [5]. This problem-based approach resulted in students' final presentations or charrettes to faculty and industry stakeholders through which they showcased design conceptualizations demonstrating application of holistic design experiences [6].

The research employed a validated thematic and qualitative analysis of the experiences of the engineering students and co-instructors in the interdisciplinary course component. Validation of the analysis was achieved through an additional person corroborating the observed themes. Data sources included questionnaires, observed discussions, and student deliverables. In addition, a survey of successful co-teaching traits was administered to the co-instructors. The effectiveness, challenges and proposed changes to this course are presented. Generalizability is limited due to the small sample size.

Literature Review

The background for these collaborative design projects builds on frameworks from interdisciplinary or integrated teaching and learning (architecture and engineering), problem-based learning, and co-teaching. In the following paragraphs, perspectives from these frameworks are elucidated.

Interdisciplinary and Integrated Teaching and Learning

Interdisciplinary or integrated teaching and learning (architecture and engineering) provides a lens to view teaching and learning across these two STEM disciplines. Researchers have noted higher levels of self-perceived design thinking traits in architecture students as compared to civil engineering students due to different teaching methods that the students are exposed to (e.g. studio being implemented in only the architecture discipline) [7]. To overcome the perceived design thinking shortcomings, attributed to the engineering curriculum, Todoroff et al. [7] noted valuable features that come from studio-based learning common in architecture programs. Civil engineering students also need opportunities to develop their creative skills and divergent thinking. Low divergent thinking in students is also observed in professional engineers, causing them to focus on one solution at the expense of exploring others [7]. Architecture students commonly learn in studio-based classes which promote creativity and provide repeated opportunities for feedback and critiques, often informally, as they work on projects [7]. Architecture students also benefit from interdisciplinary work, such as overcoming noted trouble with creating realistic designs [8].

There are a few documented attempts at interdisciplinary courses that involve architecture and structural engineering students [9-14]. Interdisciplinary education in engineering and architecture is not without its challenges, both in terms of implementation and assessing effectiveness and whether the results of one integrated experience would be transferable to another [15, 16]. These researchers often used surveys and examples of students' work to show how course structure supports the courses' pedagogical effectiveness. These courses often include co-teaching, a studio-based component or a series of projects or problems (problem-based learning), where students work in teams.

Problem-Based Learning (PBL)

Problem-Based Learning (PBL) has become a fundamental approach in education, especially within engineering and architecture disciplines, due to its emphasis on solving real-world problems through curriculum integration. The essence of PBL lies in its ability to bridge the gap between theoretical knowledge and its application, fostering an environment where students engage in meaningful projects that mirror professional practice. This educational approach emphasizes interdisciplinary collaboration, community engagement, and sustainability, which are crucial for addressing today's complex global challenges [17], [18], [19]. PBL not only enhances students' technical skills but also cultivates soft skills such as teamwork, leadership, and ethical reasoning, thereby preparing graduates to be more adaptable and responsive to the needs of a rapidly changing world and the workplace [20], [21].

PBL has been criticized because students rarely get to see the proper solution, which would allow students to identify their errors in thinking [22]. This is especially important for students to do if they have not truly mastered the fundamentals [22]. PBL has been noted for imparting cooperative skills to students while obtaining the same learning outcomes as those obtained from traditional pedagogies [23]. PBL has also been praised for being more effective than traditional pedagogies [24].

Co-teaching

Co-teaching has the potential to promote pedagogical change and shifts in instructional practice [25]. Noted pedagogical changes include adopting an interactive approach to teaching, developing a critically reflective teaching practice, developing teaching knowledge, and shifting instructors' thinking about students and teaching. Hagg and colleagues [25] argue that co-teaching can be a lever for pedagogical change characterized by new ways of thinking and the use of evidence-based instructional strategies. They further challenge institutions to transform co-teaching into a systematic approach for pedagogical change. Other researchers identify essential elements that support effective co-teaching. One study [26] identified five elements of successful practices: communication, relationship, classroom applications, planning, and knowledge of co-teaching. Though this study was set in a formal co-teaching arrangement as part of a student teaching semester in education, the findings can be applied to other settings including higher education. Communication includes active listening and intentionally addressing communication strategies. Relationship emphasizes respect and trust along with being able to adjust quickly and accept different teaching styles. Classroom applications include sharing leadership and control of the class. The knowledge base of co-teaching encompasses understanding co-teaching strategies and the support and training provided by the institution. Outcomes of co-teaching clearly support the use of this approach in STEM areas such as engineering and architecture [27], [28], [29].

Methods

The student participants included architecture students who were in a four year, 128 credit hour, pre-professional Bachelor of Arts in Architecture degree program. These students were enrolled in *ARCH 3101: Architectural Design Studio V* during their third year. This studio had three main projects in which the students integrated site, program, and structural demands into creative and aesthetically pleasing building designs. The engineering students (both master's and doctoral candidates) were part of the graduate program in the Department of Civil and Environmental Engineering. The engineering students were enrolled in *Structural Systems (CEGR 6226 or 8226)*. The course focuses on structural systems, load flow, configuration, and requirements for static stability.

The *Structural Systems* course was co-taught by an engineering professor from Civil and Environmental Engineering and an architecture professor from the School of Architecture. Both professors have had educational training in the subject matter and fields of both architecture and structural engineering. They also have technical experience working with professionals in both fields. There were five students from Civil and Environmental Engineering: two females (master's) and three males (two doctoral, one master's). The five architecture students were all third-year undergraduates (two females and three males).

The collaborative design project with a final report comprised twenty-five percent of the course grade for the engineering graduate students. The students served as structural engineering consultants to the undergraduate architecture students. One engineering student was assigned to one architecture student. The student pairs were required to meet on their project a minimum of three times (most pairs chose to meet more often). The undergraduate architecture students, with support from their assigned engineering advisor, were expected to defend their design in a presentation in front of a review panel consisting of faculty (from both architecture and engineering) and practicing architects.

The project was assigned in early November and entitled "Engineers are from Mars, Architects are from Venus," a nod to the collaborative experiences of both the graduate structural engineering students and the architecture students as they worked on their studio design projects. This collaborative work was intended to require engineering students to work outside their comfort zones, where they often needed to use the dormant side of their brain to discover skills that they may not even recognize they possessed. This would hopefully open up new possibilities in their thinking and engineering skills. The project centered around the architecture students' final designs for their Social Creative Resource Centers (SCRC), located at one of three waterfront sites in Seattle, WA. The SCRC could consist of multiple independent buildings. The resource center would engage the public and serve disadvantaged communities such as the homeless and runaway youths. Design constraints included inclusion of a makerspace with a minimum span of 60 feet and having an exposed structure utilizing mass timber. The structural aspects of the designs benefited from the collaboration with the structural engineering students. Through this work, the student engineering consultants needed to understand the design project and evaluate the feasibility of the proposed structure. Engineering consultants provided the architects with structural analysis, feedback, and recommendations for improving both the structural aspects and feasibility of the design conceptualized by the architecture students. Structural aspects that were required to be addressed through this process included vertical and horizontal load paths, structural layout and logic, ensuring general structural stability, and member sizing for a typical bay in the architect's design. The engineering and architecture pairs also discussed the project with the co-instructors, during which the scope and expectations of engineering students were reinforced. Engineering students were able to ask questions, so they better understood the design intentions of the architect and arranged future meetings.

During the *Structural Systems* course lectures, the engineering professor taught the students detailed structural analysis and design (of rigid and flexible diaphragms, shear walls, and stability considerations). The architecture professor provided the engineering students with the architecture perspective on design, and the vocabulary and rules of thumb that architects use to design their concepts. The architecture professor provided insight into the aesthetic considerations made by architects. He also used photographs of built structures, illustrations, and physical models to demonstrate key structural concepts, and identify structural systems and components.

Data Collection and Analysis

The student survey focused on perspectives about experiences during the collaborative project and included five open-ended questions focused on team collaboration guidelines from project-based learning assessments [30] including planning and decision making, communication, contributing ideas and information, and monitoring effectiveness. Based on these five guiding questions, the researchers constructed a set of fifteen related items with a Likert-scale for each item. The team reviewed and revised the items to address issues of quality [31]. The responses from the open-ended questions were independently analyzed thematically by two researchers [32], [33]. This initial process identified similar phrases allowing grouping of related segments and assignment of a descriptive tag. The Likert ratings are not used in this study due to the small variability in ratings and the small sample size of five respondents. A third individual, not affiliated with the project, reviewed the thematic codes to verify reliability. All discrepancies were resolved in a consensus meeting. The engineering students' final projects were analyzed to identify key characteristics of their products. Researchers reviewed the five submitted reports and discussed components of the reports resulting in the identification of common characteristics across the submissions [34], [35].

The engineering and architecture faculty co-instructors completed a co-teaching survey modified from the paper *What Makes Co-Teaching Work* [26]. The instrument included items related to the five elements identified from the research literature: communication, relationship, classroom applications, planning, and knowledge of co-teaching [26]. In addition, five open-ended items were added to encourage the co-instructors to describe their experiences related to these five elements.

1. Communication includes active listening and intentionally addressing communication strategies.
2. Relationship emphasizes respect and trust along with being able to adjust quickly and acceptance of different teaching styles.
3. Classroom applications include sharing leadership, control of the class, and demonstrations.
4. The knowledge base of co-teaching encompasses understanding strategies and processes for effective implementation.
5. Planning includes co-design of lesson components, instructional and assessment strategies, course expectations, and the integration of all these aspects into a cohesive course.

For each item, the average rating (1 to 6) for the two co-instructors was computed and the open-ended items were analyzed for patterns and tagged with labels for themes.

Results

The results are organized around each of the three research questions.

Research Question 1: How did students describe their experience?

The survey data provided insights related to how students described their experience in the collaborative project. A thematic analysis of the open-ended responses resulted in five major themes: Student Needs and Knowledge Gained; Communication and Empathy; Perspectives on Project Rubric; Professor Guidance; Recommendations from Engineering Students to Partner. These themes are described in Table 1.

Table 1. Themes from Student Surveys

Theme	**Description**
Student Needs and Knowledge Gains	Identified partner needs related to the project and how knowledge changed over the project
Communication and Empathy	How team members communicated with each other and empathy that engineering students developed relative to the architects’ culture
Perspectives on Project Rubric	Recommendations for changes to the rubric or project implementation and how the project reinforced current knowledge
Professor Guidance	Guidance professors provided to students related to project components
Recommendations from Engineering Students to Partner	Engineering student recommendation to architect students related to project specifications

Student Needs and Knowledge Gains. This theme underscored the needs of the architecture students. In the process of supporting the architecture students, the engineering students gained structural and architectural knowledge and an understanding of the knowledge base of their architecture partner. For example, architecture students constructed plans for their building design demonstrating a knowledge of structures. An engineering student noted that these were sometimes “Bare bones - skeleton structure that was supporting intricate and complex features.” The students were able to articulate major concepts such as the building and its function to society, and the architects’ philosophy and how the architect developed their model and plan from early ideas. Students shared that they were learning to design with a new material (mass timber). Some of the structural designs were novel for the engineering students. In working with a tent structure, a student noted “While I was aware of tent structures in general, I have not had to deeply consider how to design one [prior to this project].”

Communication and Empathy. The importance of communication and empathy were important to the student pairs as they collaborated on the structural aspects of the planned center. One student shared, “We were productive, respected each other’s time and ideas when we spoke, and kept a positive attitude.” Another student noted “collaboration is key for this project.” Empathy was also evident. For example, on student stated, “I was surprised and appreciative to see the amount of forethought that had gone into the project”.

Perspectives on Project Rubric. Students wrote about how the project rubric could better address project requirements. One concern was the open-ended nature of the project. “Since this is an open-ended project, it is difficult for me to determine what is required of me. I am supposed to come up with member sizes and connections but only on a ‘conceptual level’ that are not ‘code compliant- full construction- design package’ calculations. I am not sure where the line is for me and my work.” Concerns included having a clear scope of required work, more time to research, and starting the project earlier. Students’ perspectives also showed positive experiences. “I appreciate the uniqueness of every project when they were all given the same initial prompt which forces creative solutions from the engineering students end.”

Professor Guidance. Students acknowledged the professors' important contributions as they helped the students conceptualize how to narrow the scope and focus of the project and how to approach their problems. The professors walked around the room and talked with the pairs and provided time during lectures for students to voice their concerns and offered them feedback. The professor's mentoring “brought new insights to the projects.” “However, after my [final review] presentation, [the engineering professor] posed a few questions and introduced a few alternative designs that challenged me to think and get out of my rigid way of thinking. Those questions were very beneficial.”

Recommendations from Engineering Students to Partner. The majority of recommendations focused on adding elements for stability and sizing members (columns, beams, and shear walls). Engineering students worked to accommodate design changes initiated by the architecture students. “Initially there was no overhanging and now after a final review, we have a cantilever balcony. Hence, I have to update my recommendations.” These recommendations also provided insights into students’ extension to engineering understanding. “I would say I made two (2) suggestions that were outside the realm of structural engineering. One of which was concerns for foundational integrity while the other was addressing amenities and commodities within the housing structures."

Research Question 2: What are the characteristics of the students' final projects?
Design projects for the Social Creative Resource Centers (SCRCs) were in a high seismic zone with three potential waterfront site options set in Seattle, Washington. The centers were constructed primarily of mass timber with a required 60' span and an exposed structure to be placed in the makerspace section. Architecture students had developed their conceptual design to quite a high level before the engineering students joined. Descriptions of the design concepts created by the architecture students before the collaboration with the engineering students is presented in Table 2. Engineering students were challenged to provide insight with resolving the structure.

Table 2: The architecture program of the SCRC designed by the architecture student of each team.

Group Number	**Architecture Program of the SCRC**
1	Provide a science center, creative space, and educational exhibits for the Seattle, Washington community. The complex consisted of three similar fan-like structures - the engineering student focused on one structure.
2	A fishing pier to teach the homeless fishing to develop career skills for the area's large fishing industry, and classrooms for developing understanding of ecosystems and conservation. The makerspace is an industrial kitchen that will be used to cook caught fish.
3	Shelter for runaway kids in Seattle, WA in a waterfront area surrounded by gardens and farmlands
4	Provide the homeless with shelter and amenities and a venue for meetings and classes. The design contained a makerspace (for learning) with an accessible green roof, a dormitory building with restrooms, and a building with laundry, kitchen, and dining amenities. The engineering student worked on the makerspace component only.
5	The architecture student incorporated an existing fishing dock for the homeless population. The homeless would then be able to sell their fresh catches to the public at the makerspace section. The elevated fabric roof structures served as the residential complex for the homeless. See Figure 1.

The five engineering students' final reports were analyzed and coded by two researchers, resulting in three themes corresponding to those identified from student surveys: Student Needs and Knowledge Gains; Communication and Empathy; Recommendations from Engineering Students to Partners. Examples are used to provide a rich description of these characteristics.

Student Needs and Knowledge Gains. Engineering students consulted ASCE 7-16 to determine the appropriate design loads (whether that be Dead, Live, Roof Live, Wind, or Snow) and NDS 2018 or ANSI/APA PRG-320 for sizing the timber members. One student elaborated on her knowledge growth, "Not only did I have to learn a new subject that I had no experience with, mass timber, I also improved my research skills while looking for more resources on mass timber. With mass timber being more recently introduced to the industry, finding accurate information took some time and patience." Another (Group 5) discussed not being able to resolve a challenging tent system in time: "Structurally, the only main issue that [I] was unable to fully resolve in time was anchorage for the cables in the fabric roof system. Conceptually, the structure is adequate." This unique tent system is illustrated in Figure 1 which underscores the effective use of diagrams and highlights the critical role of understanding interpreting graphics.

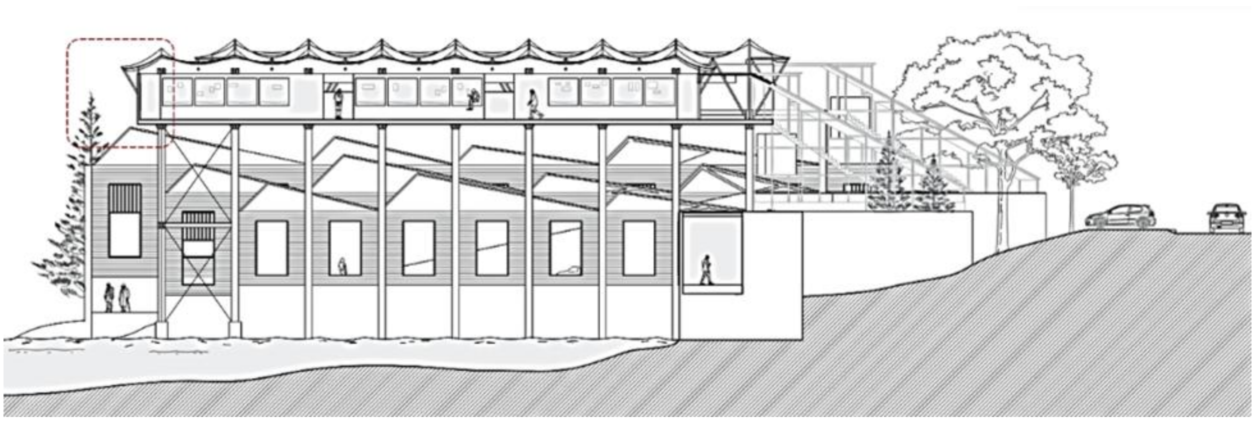

Figure 1. A transverse elevation view of the SCRC designed by the architecture student in Group 5. There are three elevated housing units with a fabric roof system, making it one of the most unique designs created by any of the five architecture students. There are also two multipurpose buildings, one being the marketplace (makerspace). The architecture student's precedents were the elevated tents designed by architect Peter Zumthor and the Denver National Airport's fabric roof system.

Communication and Empathy

Students realized the role of communication and empathy as part of professional growth. "Communication was vital for me to be successful during this project. I would reach out to find out beam spans and column heights. [My partner] would always get back with me in a timely manner. The in-person meetings really helped me gather my recommendations to present nicely to [the architecture student] in a manner that we both agree on." Students also included challenges in their reports. In one clear illustration, a student described how her partner did not always accept the recommendations that she made. The report suggests that there were communication challenges and areas for improvement, or that the architecture student did not value her contributions. In this case, the architecture student removed columns that were significant to the structural integrity of the building, on the day of the final review. "[The architecture student] was concerned with the visual appeal of the building. When I would make suggestions or recommendations, he would consider how it would affect how the building would look. There were also suggestions that I noticed at the presentation that I made to [him] that were not taken. For example, I had suggested widening the staircase because there were columns around the staircase and then right next to it columns supporting the beams. He widened the staircase but took out the columns that were needed to support the beams overhanging on both sides of the staircase. … Something I am taking away from this experience is to be more assertive when it comes to making suggestions that are necessary for the structure."

The development of professional empathy is the ability to understand and share feelings in a professional setting. According to Walther and colleagues [36], empathetically engaging with a range of stakeholders is an increasingly important part of the expectations of a professional engineer. They [36] "conceive empathy as, concurrently and inseparably, a teachable skill, practice orientation, and professional way of being … enabl[ing] students and engineering practitioners to more holistically and thoughtfully engage with the complex, socio-technical challenges that characterize the current age" (page 124). One example of professional empathy from the reports is when an engineering student took the initiative to suggest replacing the architecture student's originally envisioned steel beams in a specific section of the building with mass timber beams to "satisfy the project requirement of using mass timber". She further suggested making these mass timber beams overhang, thus eliminating certain columns and thereby creating an unobstructed view from this section of the building. An interesting discussion observed between one pair (Group 5) was about the placement of the unhoused under a fabric roof structure reminiscent of tents that the homeless were unfortunately probably too accustomed to in their lives. The engineering student felt adamant that this was not a good idea, yet the architecture student was steadfast on the design due to its creativity. The engineering student also put this disclaimer into his final report: "As a general disclaimer, this projected idealization is geared with the intent of providing housing for the homeless while also incorporating community engagement. This involvement however is not meant to develop the insinuation that the homeless are exploited by leveraging them into a form of indentured servitude (e.g., providing housing by profiting off the fish marketplace)."

Recommendations from Engineering Students to Partner based on Architecture Student's Need

Recommendations ranged from sizing CLT panels, joists, girders, king posts, roof trusses, bracing, cables, glulam columns and beams, a flitch beam, slab thicknesses of overhanging floors to providing recommendations on lateral stability under the governing seismic conditions. Approaches for ensuring stability ranged from changing the type of diaphragm to designing MSR lumber shear walls or designing the vertical and horizontal reinforcement of concrete walls to resist seismic loads. Students also considered buckling and deflection limitations, determined maximum overhanging distances, suggested materials to use, and suggested either changing the spacing or adding more columns, beams, and walls to the layout if deemed structurally necessary. Table 3 summarizes the recommendations and resulting changes that were made by one pair.

Table 3. A schedule of the engineering recommendations and changes made by the architecture student. Table from the final report of the engineering student (Group 5), emphasis is his own - not added by the writers of this paper.

Date	Recommendation/ Suggestions	What Changed
Nov 9	● Pull proposal structures back from the shore towards mainland ● Site soil condition concerns and considerations for foundation design ● Terminate concrete wings/retaining walls to shoreline ● Consider utilities & appurtenances for tent structures ● Consider an alternative roof system for housing structures ● Consider alternative roofing system for the marketplace	● Proposed structures were receded further mainland ● SSI (soil and structure interaction) & foundation concerns are outside scope of project ● Wings were drawn back from waterline
Nov 16	● Consider using roof trusses as support to fabric roof ● Implement shear walls to frame marketplace over columns ● Cables in fabric roof need anchorage into ground	● Architecture faculty **strongly encourages** the development of a fabric roof system ● Do not want cables impacting/distracting the surrounding structures
December 1	● Use a pulley system to redirect the cable anchor load	● Marketplace was framed with shear walls. ● Marketplace had solid roof and roof trusses. ● Lateral bracing was incorporated into housing structures. ● Redirected cables.
December 7	● Cable forces on timber columns are too great for designing snow and wind loads. ● Minimum prestress forces are sufficient, however.	

Research question 3: How did the engineering and architecture co-instructors describe the strengths of co-teaching?

The two instructors completed a teaching survey to better understand their impressions of the co-teaching implementation. The survey focused on five interrelated components that are viewed as essential for an effective co-teaching model [26]: planning, communication, relationship, classroom applications and co-teaching knowledge. Data from the Likert (6-point scale) presented in Table 4 presents the average ratings, on a 6-point Likert scale for each of the five focus areas. The two co-instructors also wrote comments throughout the survey to elucidate their thinking about the item.

Table 4. Co-teaching Survey Results

Elements	**Averages**	**Question Numbers**
Classroom Applications	4.9	1, 8, 10, 12, 14
Relationship	5.6	3, 15, 17, 18, 19
Communication	5.4	4, 7, 9, 11, 21, 22
Planning	5	2, 5, 6, 16
Knowledge Base of Co-teaching	4.92	13, 20, 23, 24, 25, 26

The survey results confirmed an effective framework includes active listening and use of communication strategies, respectful relationships built on trust and acceptance, sharing leadership in classroom applications, collaborative planning and sharing roles, and a knowledge base reflecting an understanding of strategies and process for co-teaching. There were two elements with survey averages above 5 (out of 6) indicating strong alignment with instructor practices. Communication has an average of 5.6 underscoring active listening as a practice, and relationship has an average of 5.4 showing both co-instructors believed in respect and trust with an appreciation for the skills each brought to the collaboration. Instructor comments also showed that they view their relationship as a partnership connected to their shared leadership in co-teaching the engineering course as well as the collaborative project involving the two courses.

Comments from the open-ended item responses are characterized by a belief that the success of co-teaching depends on a complex and mutualistic relationship between the two co-instructors. One survey item was given nonadjacent ratings: “Planning specifically and not in generalities” with ratings of 4 and 2. Comments reconcile these differences: “We do both - plan specifically and generally. Specific planning regarding the minimum course content and associated presentation. General planning in that we can adjust presentation and conversation topics to respond to students’ issues and interests.” Six questions addressed *communication* with the average of the five communication questions 5.4 on a 6-point Likert scale. Both instructors rated “Communicating honestly with my co-teaching partner even when it is difficult” as a 6. One instructor commented that “communication can involve encouragement and voicing concern”. Active listening is a primary characteristic of effective communication in co-teaching.
Five questions providing information on *relationships* with an average rating of 5.6. Two questions were answered variably: “Adjusting in the moment - making changes as we go along” with 5 and 6 ratings, and “Stepping in when my co-teaching partner needs assistance” with ratings of 3 and 6. One instructor shared that stepping in “might be important generally, but this has not been an issue in this course. We step in when we want to make a counterpoint or complementary statement.” There were 5 questions connected to *classroom applications* with an average rating of 4.9. Two questions were given nonadjacent ratings: “Using co-teaching strategies to differentiate instruction.” with ratings of 4 and 6; and “Handling interruptions without stopping the class” with ratings of 3 and 5. An elaboration was “I believe this [using co-teaching strategies to differentiate instruction] is more important than my rating suggests, but this

comes so naturally working with [co-instructor]. As we are open to each other's teaching styles and the different ways we view the same problem. In other words, our strategies are implicit." "It is more of a partnership than a hierarchy" which leads to "more fruitful conversations. Students often hear two views - left brain versus right brain - on the same topic."
The *knowledge base of co-teaching* mapped to 6 questions with an average rating of 4.92. Ratings for one question differed by 3 points "When leading instruction, the instructor assigns tasks and responsibilities to the co-instructor and other instructional assistants" differed by 3 points (ratings of 3 and 6). "I provide the minimum course content as would typically be taught in an engineering class by an engineering faculty; however, [co-instructor] expands upon the content and fills in gaps by presenting similar material through the eyes of an architect. This encompasses the true beauty of the course. In summary, instead of tasks and responsibilities being assigned, they are organically carried out. The architecture professor commented that "the collective technical expertise as well as diverse presentation techniques create a solid foundation for a strong knowledge base."

Discussion

The engineering student surveys included insights into the knowledge gained from the experience, the role of communication during the project, and the significance of guidance from professors. The study showed that the engineering students appreciated their partner's role in providing them with a window into the engineering and architecture relationship that exists in real-world contexts. The responses reinforced the critical nature of communication and empathy in successful integrated design with students acknowledging how this experience built important soft skills such as communication and time management. One of these critical byproducts was negotiating - learning how to reach a compromise to better the design. Professor mentorship as co-instructors was a positive feature with responses showing how professor guidance supported understanding the scope of the project and narrowing the focus. Through these experiences students experienced new insights that increased their understanding of tackling complex real-world design problems. The reports from the graduate engineering students also highlighted experiences with communication and the development of empathy, recommendations made by architecture students to the architecture students, and knowledge and skills learned. The vital role clear communication played in the success of the project and how effective communication assisted in considering information and allowing discussions to move toward agreement or compromise was touted as a necessary skill with one student recognizing that this project exposed them to experiences mimicking the world of a structural engineer. Ideas for next steps also emerge from the project data. Interest in co-teaching and its application should be further explored with focus groups involving additional architecture, engineering, and other STEM faculty. Some recommendations to deal with student resistance in interdisciplinary projects that are open-ended – requiring design alternatives and iterations: engaging former students as speakers to reassure the class that the project is achievable in the allotted time and share artifacts from their report to demonstrate the extent and expectations of the project; assigning short problem-based assignments earlier in the course that deal with architecture and structural system integration; provide discussion and exemplars with students in advance of the project to develop ideas about approaching the analysis and resolution of structural components. Both the student and co-instructor data consistently demonstrated the benefit of this experience and provides key evidence for continuing and expanding opportunities for co-teaching and real-world interdisciplinary problem solving.

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