Building Technology Educator's Society

Volume 2019 Article 38

6-2019

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Recommended Citation

Laboy, Michelle and Onnis-Hayden, Annalisa (2019) "Bridging the Gap between Architecture and Engineering: a Transdisciplinary Model for a Resilient Built Environment," *Building Technology Educator's Society*: Vol. 2019 , Article 38.
DOI: https://doi.org/10.7275/mr5p-8x02
Available at: https://scholarworks.umass.edu/btes/vol2019/iss1/38

Bridging the Gap between Architecture and Engineering: a Transdisciplinary Model for a Resilient Built Environment

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Abstract

As the focus of environmental engineering increasingly shifts to landscape-based, decentralized solutions to energy and water; and as architecture increasingly shifts its attention to resilience, ecological connectivity and independence from centralized infrastructure, these two disciplines find themselves closer in scale than before. This paper presents a collaborative project between upper level architecture and environmental engineering students focused on the design of sustainable and integrated water systems. Critical features of transdisciplinarity included: the engagement of stakeholders in the process at multiple moments; the speculative nature of working on very distant futures, the multi-scalar requirements of the collaboration, and the expectation of balancing quantitative and qualitative performance criteria. The curriculum was successful by many measures of work quality and impact. Students reflected on expectations and outcomes at two points of the semester, providing insights on challenges and opportunities. Relying on a shared responsibility for the project and well-aligned touchpoints, rather than daily-integrated studio-format, overcomes administrative constraints, but made misalignments more evident. While initially students had higher expectations of learning about the *other* discipline's role than about their own, later results clearly show many more thought they had learned more about *their own* discipline, and expressed more confidence on their joint work. This is an encouraging finding about the power of transdisciplinary educational experiences.

Introduction

Calling the term overused, architect Bernard Tschumi was quoted as saying that collaboration worked well when everyone had defined roles –"not one of those artificial things where everyone is being creative together".[1] While perhaps cynical, this comment highlights that effective interdisciplinary work is built on deep disciplinary expertise. Nonetheless, today's context of crisis presents designers with complex problems that necessitate integrated solutions. A recent historiography of architecture and science defines interdisciplinarity as vocational cracks that happen in moments of crisis, "opening up alternative lines of inquiry that in turn enrich our vocational understandings;" [2] a suggestion that professionals learn more about their own discipline by understanding the work of others—a provocative idea for educators. Bringing different disciplines into a project team early in the design process is required to build that understanding, but it alone may not lead to the integration necessary to address the more complex contemporary problems. This is especially true if design professionals do not have the skills or understanding to adopt each other's methods of inquiry and forms of knowledge. While interdisciplinary collaboration can begin to break down the silos in design education (architecture, engineering, urban planning, etc.) its shortcomings become more evident when well-intentioned efforts rely on self-contained modes of research, which are then brought together. To address this shortcoming, design education could engage with the notion of transdisciplinarity, which promises to hybridize knowledge and modes of inquiry to move "beyond putting things together." [3].

A transdisciplinary approach should result in more than the sum of the individual disciplinary knowledge,[4] thus new pedagogies for design education should make evident how traditional curricular approaches are opened up to new questions and forms of input. For example, transdisciplinary research expands the idea of different disciplines working jointly with the addition of external non-academic or non-professional perspectives from society.[5] While this has the potential to better address the more challenging and complex social and environmental problems in practice, it represents a challenge to design educators that usually rely on defining a more narrow and speculative problem to provide more clear learning outcomes. That being said, there is momentum building around the idea that design education needs to, and is well positioned to, embrace a higher level of complexity and hybridization. Architecture and urban planning are considered fertile territory for transdisciplinary work because they are action-oriented and focused on multi-dimensional problems.[6] Similarly, calls for engineering to engage transdisciplinarity emphasize their focus on design, process and systems in the application of skills and knowledge to unstructured problems. Scholars of teaching and learning in design disciplines can advance transdisciplinary teaching and practice by testing and disseminating innovative pedagogical experiments, building a body of evidence for when, where and how to most effectively create hybrid curricula. This paper presents findings about teaching methods, learning opportunities and overall challenges that were discovered while implementing and assessing a transdisciplinary design project between two courses in architecture and environmental engineering.

When reviewing the literature, a few characteristics of transdisciplinary research pointed the teaching team towards key elements to effectively bridge between architecture and engineering education, including: a focus on real-world problems and their solutions; acceptance of uncertainty and local constraints from social, organizational and material contexts; the bridging of theory and practice; and the connection of research and societal decision-making.[7] Two capstone design courses mapped shared learning goals and milestones for team projects focused on sustainable development, specifically addressing the nexus of water and energy, which operate at multiple scales from buildings to urban infrastructure. The goal was to systematically observe how students hybridize knowledge through collaboration on a complex and multi-scalar design problem; and to evaluate how this pedagogical model may better prepare future professionals to build more resilient environments.

Urban water: a context for transdisciplinary design

This collaboration was inspired by a student-initiated extracurricular project at Northeastern University for the Rainworks competition of the Environmental Protection Agency in 2015. The student team, mentored by the authors of this paper, won an honorable mention—ranking 3rd out of 48 projects nationally. The project engaged multiple disciplines and community stakeholders, providing a transformative experience for everyone involved. This water design problem generated a level of student motivation and effort that inspired the faculty to experiment with more transdisciplinary models within the core curriculum.

Global patterns of urbanization demand new paradigms for sustainable urban water resources, emphasizing integrated water management for environmental quality, economic prosperity, and social development; and requiring improved coordination between engineers, urban planners, architects, and city administrators to replace water import and export with more localized supply and reuse.[8] As a result, the focus of environmental engineering increasingly shifts to landscape-based, decentralized solutions to energy and water; while the focus of architecture is increasingly shifting towards resilience, ecological connectivity and independence from centralized infrastructure through site- and district-scale solutions. These disciplines traditionally operated at two extremes in scale but are now closer than before.

According to the National Academy of Engineering, the multifaceted and multidisciplinary challenges of sustainability can introduce students to interdisciplinary learning by working to solve complex, interdependent, global problems.[9] However, a review of the literature on design education found only a few truly interdisciplinary collaborations focused on sustainable development; which included civil, construction, environmental, agricultural, biosystems, electrical, computer, chemical, and mechanical engineering, as well as landscape architecture and organic agriculture; [10,11,12] but not architecture. This is surprising considering the significant role that buildings play in the consumption of energy and water. On the other hand, most known collaborations in architecture are with structural engineering, as evidenced in detailed accounts from practitioners.[13] Many of these documented examples are limited to the building scale, working with allied disciplines of architectural and structural engineering; arts, landscape, and health; while other examples that expanded to urban scale issues worked with landscape architecture, urban geography or planning, but not engineering.[14,15,16] Similarly, interdisciplinary capstone projects are not a new or innovative practice in engineering education;[17] but few engage environmental engineering with other disciplines.[18] Indeed, cross-disciplinary design in civil engineering is often limited to its sub-disciplines of environmental, structural, geotechnical, transportation and water resources. This suggests that a curricular experiment between architecture and environmental engineering would not only be motivating to students and potentially relevant to the future of practice, but that it also demanded a careful analysis of learning outcomes.

Methodology

There are two methodologies to describe about this project: the teaching methodology and the research methodology, which happened concurrently and informed each other. The first involved designing a curriculum, documenting challenges and opportunities, and making observations from the outcomes of the student work. The second part involved understanding current practices, identify existing evidence, and refine remaining research questions; as well as measuring both student interest in and perceptions about their learning. We surveyed the students at the start and at the end of the collaboration, asking the same questions to both disciplines. We analyzed the distribution of responses to quantitative questions and coded ideas emerging from qualitative/ written answers; making comparisons between initial and final surveys, as well as between disciplines. These two parts of the work, the teaching observations and the student surveys, provided the foundation for a pedagogical research analysis. The following sections of the paper explain the design of the curriculum to provide context; followed by key observations from the faculty about important moments of learning, specific challenges, potential solutions and/or opportunities for future research; and finally an examination of the results from student learning surveys.

The faculty's prior experience in project-based teaching, their alignment of interests, and the ability to make changes in the curriculum is critical to the feasibility of this type of experiment. In this case, the Architecture professor is a researcher on architectural aspects of socio-ecological resilience, who teaches and coordinates Comprehensive Design Studio, and has taught collaboratively with landscape architects on ecological issues. The environmental engineering professor is a researcher on sustainable wastewater treatment solutions and integrated approaches to water, who teaches the environmental engineering capstone and previously had included building developers as clients in student projects. The students in these courses were a combination of seniors and graduate students from architecture, and seniors from the Bachelor in Science in Civil & Environmental Engineering. In these required courses, the students in these particular sections were only a subset of the two classes, and therefore were self-selected. This allowed the faculty to gauge initial interest and perceptions of students opting into the project, but also allowed students to be aware of and motivated by the experimental nature of the curriculum.

A pre-semester survey measured whether there was student interest in collaborating with other disciplines. Nineteen of the twenty-one civil engineering students that registered for the Environmental Senior Design Project answered the question: “Are you interested in being part of a multidisciplinary team?” Six responded “yes”, twelve responded “maybe”, and one student responded “no.” This survey showed significant curiosity about this type of collaboration, but the large percentage of students that responded “maybe” indicates that there was some uncertainty about what it would entail. In architecture, fifty-five students were already divided into twenty seven groups (mostly pairs) and given a description of five different sections of Comprehensive Design Studio, including two interdisciplinary collaborations with engineering (the subject of this paper with environmental engineering and another with structural engineering). Nearly half of the class (48%) expressed interest in one of the two interdisciplinary sections. Just over a quarter of students (26% of the total class) expressed interest in the collaboration with environmental engineering. These numbers are remarkable considering the experimental nature of the studio, in what is already considered an extremely challenging semester. Ultimately, thirteen engineering students were paired with ten Architects in two sub-groups of twelve and eleven; although the formation of transdisciplinary teams did not happen until a month into the semester, as will be explained.

Curriculum Design: Mapping Shared Learning Goals

For building technology educators in architecture, project-based teaching within the design studio can be a powerfully-effective learning experience that increases student motivation through more formative assessments that closely resemble their personal interests and future professional practice.[19] While in engineering education, project-based learning has become standard practice and an accreditation requirement;[20] design is not as central to their daily experience as it is in architecture. Therefore, the nature of design education in each discipline is one of the first challenges to overcome. The studio model in architecture, based in a shared physical space for creation, instruction, meetings and feedback, is not typically found in engineering. The typical capstone course in engineering is the closest to the architecture studio: with precursor courses on project-based learning, sequential assignments, and strong group project emphasis.[21] While these are natural places in the disciplines’ curricula for this type of collaboration, both the teaching methods and deliverables can differ substantially. Engineering capstone courses rely on written reports with a significant amount of quantitative analysis, while the architecture studio relies on graphic visualizations and physical models. This can be a source of misunderstandings and misperceptions, but also an opportunity to build understanding.

To hybridize methods, it is necessary to identify shared learning goals. For example, the connection to “reality” of the design project has both similarities and potentially productive differences between disciplines. Active stakeholder involvement is an important aspect of engineering capstones, which is essential to transdisciplinarity, but less common in architecture education. On the other hand, the architects’ speculative approach to projects helps expand the goals of involved stakeholders and the performance criteria of the engineering project by imagining alternative futures. These alignments and differences can be found in the course learning outcomes. The syllabus of the environmental engineering capstone course requires *"understanding the problem from a client's perspective."* The architecture studio syllabus invites students to think how building systems will *"meet unknown future spatial, structural, and energy needs in response to a changing context and climate."* While most goals in the engineering syllabus are focused on professional skills (applying engineering standards and computing tools, writing effective proposals and technical reports, and giving effective presentations of technical material), one goal explicitly connects with transdisciplinary approaches: "Consideration of economics, aesthetics, sustainability, manufacturability, impact to the natural environment, ethics, social impact, political context, public health and safety."

The early focus of both courses on systems, their sustainability and resilience, proved to be a productive alignment of learning goals; a way to focus the early research on how systems and their performance may need to change over time. This prevented the architects from jumping into design too quickly following their traditional approaches while encouraging the engineers to think beyond existing conditions as governing parameters of design. Both groups of students, as will be explained, were at different points uncomfortable with or anxious about aspects of this approach, but it was important to create space for new ways of thinking. This was made possible because the Comprehensive Design Studio in the School of Architecture at Northeastern consists of four phases that reverse the typical studio sequence to foreground building systems as generative of long-lasting buildings, delaying site or program, in that order, so that solutions can follow the life cycle of systems from longest to shortest.[22] The approach moves away from "applying" technology to solve an already defined problem; instead using research-based principles on systems performance to guide the design process. Similarly, it is increasingly more central to environmental engineering capstone courses to consider the changing parameters of climate change in the systems that they design. System life cycles and changing environmental conditions are a perfect context to suspend traditional design approaches and engage in hybridized thinking.

When working within the constraints of each discipline's teaching methods, especially in courses that are so central to the accreditation of the program, it is important for the faculty to not only identify shared learning goals and opportunities for hybridization, but also to map the alignments of learning goals in the schedule, identifying moments for deep engagement, and moments to retreat into disciplinary expertise. The goal should be to clearly identify the appropriate timeframe for students to work together, and the degree of integration that is expected. This considers a unique challenge of collaboration in education: that in order to be transdisciplinary, students need to first attain a high level of disciplinary expertise that they don't yet have. The faculty hypothesized that testing the effectiveness of hybridized modes of inquiry can be better tested in the quality of the final deliverables of each individual discipline, rather than a combined deliverable where the impacts to each discipline would be more difficult to discern. With those goals in mind, the organization of course schedules and deliverables was adjusted to reserve a critical amount of time at the beginning of the semester for the students to prepare for and build confidence in their roles in their future interaction; and to provide some space at the end of the semester for the disciplines to reflect on their past interaction and develop detailed deliverables specific to their discipline.

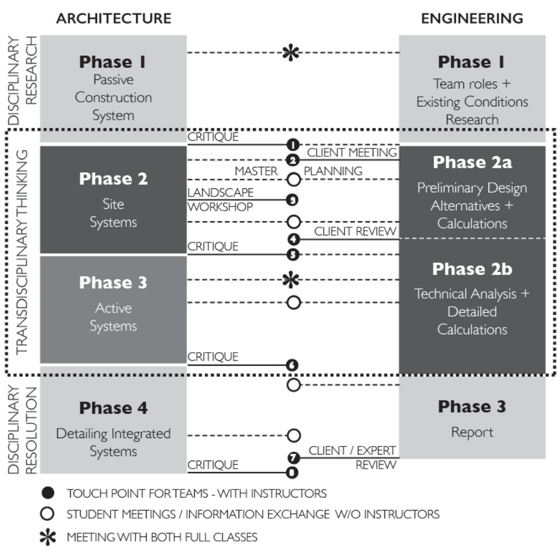

Fig. 1. Example of mapping alignments and goals for a transdisciplinary curriculum between an architecture studio (left) and the engineering capstone course (right).

As seen in Figure 1, what we called “transdiscipinary thinking” happened in the middle zone of the semester. The goals and schedules of both courses were adjusted slightly to align at the beginning of Phase 2, and for the classes to meet at important *touchpoints*, which included: (1) the forming of teams at the review of phase 1, (2) meeting with the client to listen to aspirations and set project goals, (3) a workshop with professional landscape architects to review preliminary urban design and site planning concepts, (4) Preliminary presentation to the client (5) Phase 2 critique of projects (site design) with external professionals, and (6) Phase 3 critique of architecture projects with professional architects and the engineering students as critics. Students were also expected to meet other times without the faculty and collaborate on exchanging information for the final deliverables (Fig.1).

Observations in the classroom

The projects required comprehensive master plans for sustainable districts or developments with ambitious environmental goals in Boston and Gloucester, Massachusetts; and identified a few critical building sites within the district/development to be designed in more detail either as district service buildings or as prototypes for key parts of the plan (Figure 2). Students had to negotiate the goals and requirements of individual sites with those of the master plan, develop quantitative and qualitative analysis; and model the requirements, contributions and performance of prototype buildings within the district. Architects and engineers co-authored the most critical design decisions. The faculty made observations about the dynamics of this collaboration at individual class meetings and at joint touchpoint meetings.

A joint lecture and discussion kicked off Phase 1, before architecture and engineering students formed teams. It covered important background on the topic of the projects, including the urgent global challenges and compounding effects of rapid urbanization and climate change, and design opportunities in coastal cities at the water/energy nexus through the use of inspiring examples of integrated projects. This proved to be an important teaching strategy to address the initial uncertainty. However, during the group discussion that followed students were asked about the potential of working together, and the answers were fairly predictable. The responses included ideas from the engineers about how projects with architects may be more: *holistic, inspiring, aesthetically pleasing*; and responses from architects about how projects may be more: *realistic, feasible, stronger, measured*. After that group discussion, engineering students researched and documented existing and projected future conditions of potential sites, while the architects worked intensely on researching and designing construction systems that expand what architecture can do with water. The five pairs of architects developed site-less structural prototypes for, for example, rainwater collection and storage through the structure (concrete umbrella columns), robust masonry walls thermal mass that supports heavy vegetated surfaces, folded plate structures that channeled water from the roof to rain gardens along the building edge, (Fig. 2a-c) glulam timber for long-span greenhouses housing living systems amongst uninsulated buildings, and a timber frame with south-facing atriums housing biotopes for water treatment. These prototypes were catalysts for teams to form, and to find alignments between engineering research on site projections and architectural ambitions that could structure the parts of the urban master plans (Figure 2).

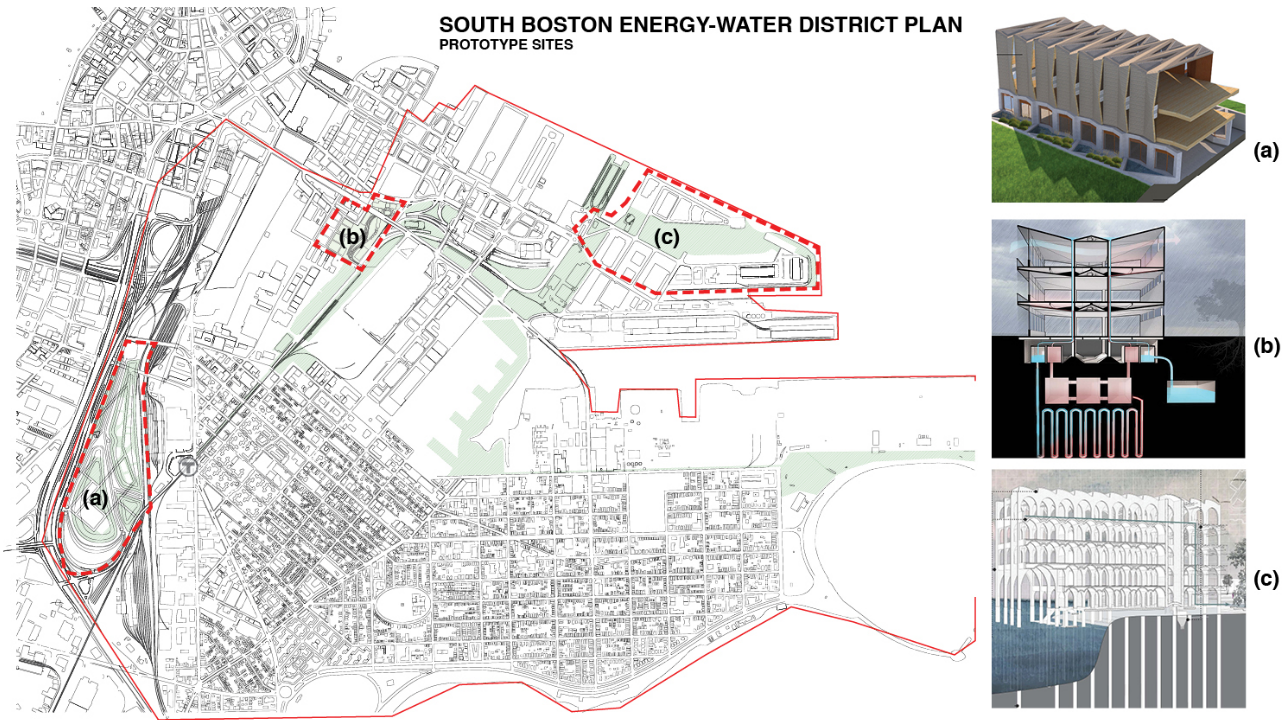

Fig. 2. Student team's master plan for Boston's Seaport district, with three architectural prototypes developed for three critical sites: (a) the Community Water and Energy Center, (b) the Green Street building of water-collecting umbrella columns, and (c) the remote grid-disconnected building that manages all water on site and is designed for storm surge.

The following phase involved intense transdisciplinary collaboration on master planning. This is where points of tension were observed. Architects moved quickly through design iterations based on preliminary data, site observations and intuitions, while the engineers were non-committal until full site data was available. The design critique with external landscape architects, an atypical format for engineering students, was a helpful touchpoint that modeled how to work diagrammatically with informed assumptions that could later be refined. Similarly, architects proposed alternatives to the client's initial requirements, based both on performance and experiential criteria; but engineers resisted the idea of not giving the client what they asked for. At one of the touch points, the faculty facilitated a group discussion about recognizing clients priorities and often competing goals, and encouraged the teams to think about ways to educate the client by presenting and contrasting multiple options for the design playing out over longer time frames. This represented a challenge for engineers who rely on fixed criteria for selecting equipment and making calculations, and for architects that usually follow a program brief. Both architecture and engineering students modeled different scenarios to design ways to enable changes in program, equipment, technologies, and engineering processes over time. Students were uncomfortable with the unavoidably slower pace of progress in a more complex process. In these expected situations, it is helpful for the faculty to provide assurances that the immaturity of the design at that stage was necessary and expected in order to later achieve more integrated thinking.

The second type of challenge involves finding shared responsibility on the project when the students traditionally operate at very different scales. The approach to this challenge was to make the larger teams jointly responsible for the urban scale planning, but architects were divided in sub-groups responsible for specific sites within each district; and the engineers were divided into sub-groups responsible for different technical components. Like a metaphor for transdisciplinarity, students had manageable projects to apply specialized expertise to, but also higher-level goals and responsibilities that extended beyond the boundaries of their individual sites.

Survey Findings

We asked the students what the other discipline brings to the table and how the interdisciplinary collaboration will make their project different than if they worked only within their own discipline. The engineers anticipated that the architects would bring creative ideas and perspectives about the culture of the project site. They expected a more *well-rounded* and *interactive* design that would better integrate design with the rest of the community (the existing buildings and the people living within), more *aesthetically pleasing* and more *fluid* and *interesting* than what they would have come up with on their own. For example, one student said "the buildings would just be squares on the plan without any real substance and stormwater structure would be mere oblong element without any other function than holding water". The architects expected more rigor and accuracy in quantifying impacts using "real" data and technical information to increase the options, capacity and scope of the architects more "diagrammatic" projects. They also expected a necessary simplification and increased focus for what otherwise would be overcomplicated or unrealistic ideas; designs that were more *functional, realistic,* and *complete*.

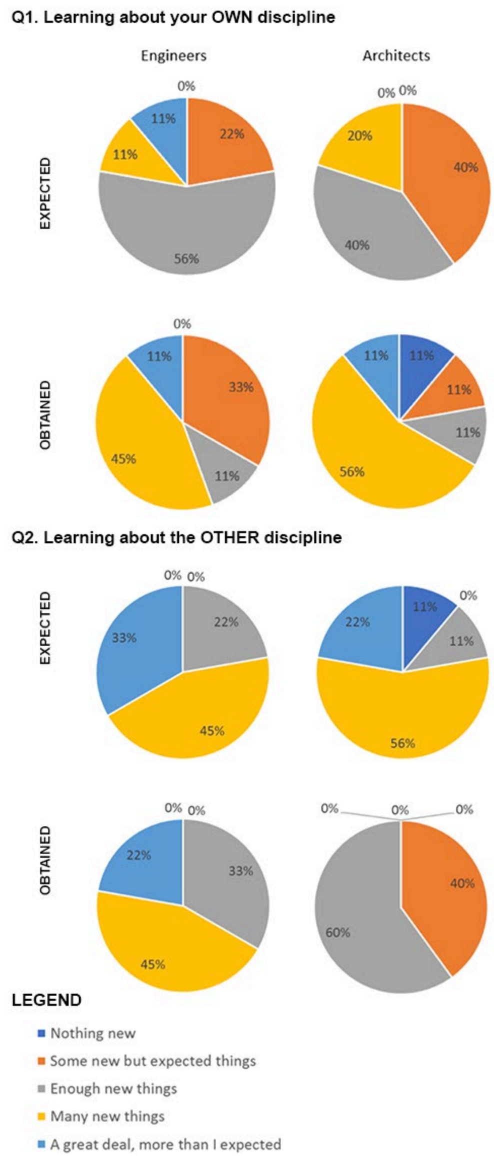

Figure 3: Survey results for learning questions about the role of the disciplines, before and after the collaboration.

When asking the students early on to quantitatively rate how much they expected to learn about the role of each discipline, the survey reveals that both the engineers and architects had higher expectations of learning about the *other* discipline's role than about their own (fig.3). Later results clearly show that the students felt that they learned more than originally expected; and most interestingly, many more thought they had learned more about *their own* discipline. This was especially true for the architects, who seemed to have improved sense of the importance of their role in these seemingly technical problems. This is an encouraging finding about the power of transdisciplinary educational experiences.

Conclusion

This collaboration was successful by many measures. Students self-organized and engaged with people from communities, including water taxi drivers in the seaport district, fishermen and food processing workers, developers, land owners and environmental groups. While slower to develop, the projects in the end achieved a higher level of technical development than previous iterations of both courses. Projects earned multiple recognitions: two awards at the Northeastern University RISE competition: an Innovation Award but also a Graduate Humanities Award; and a 3rd place in a national wastewater competition. The two departments recognized the potential for more collaboration between these two disciplines, and the need to develop hybrid practices. Two new combined majors between Civil Engineering and Architecture, and between Environmental Engineering and Landscape Architecture were proposed and approved for the coming year.

Shortcomings are to be expected with a first iteration; and should be addressed in future iterations in this institution or others. Relying on a shared responsibility for the project and touchpoints, rather than daily-integrated studio-format, overcomes administrative constraints and requires more independence and initiative on the students; but misalignments of schedule and differences in learning goals between the two disciplines were still evident impediments to more cohesive projects. Students acknowledged that the other discipline contributed to their confidence in their proposals. This type of experience is more likely to teach students something they do not expect about themselves and prepare them to negotiate new methods of working. It also provides opportunities for taking bigger risks in projects. There were a few critical features of the project that enabled transdisciplinarity: the engagement of stakeholders in the process at multiple moments; the speculative nature of working on very distant futures, the multi-scalar requirements of the collaboration, and the expectation of balancing quantitative and qualitative performance criteria. This capstone project represented a challenging but worthwhile effort for all those involved, and the quality of the proposals that emerged suggest that there is fertile territory to continue to explore transdisciplinary collaborations between architecture and engineering.

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