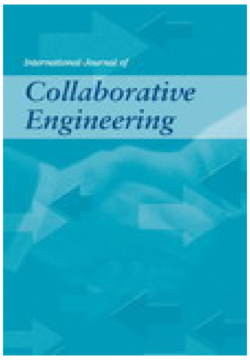

International Journal of Collaborative Engineering

ISSN online: 1745-0047 - ISSN print: 1745-0039
https://www.inderscience.com/ijce

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DOI: 10.1504/IJCE.2020.10033950

Article History:

Received:	09 October 2019
Accepted:	29 February 2020
Published online:	29 April 2026

Cross-disciplinary learning in environmental engineering and landscape architecture

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Abstract: Professional environmental engineers and landscape architects routinely collaborate in practice. However, rarely do university students pursuing these two professions interact in an academic setting. The purpose was to analyse the impact of cross-disciplinary collaboration on student learning between groups in environmental engineering and landscape architecture. This study analysed perspectives from students, teaching assistants, and instructors using open-ended survey questions, Likert scale ratings, instructor observations and engineering final project assessments. Faculty, students and stakeholders ultimately felt that the interaction was beneficial. Instructors felt the collaboration generated potential for higher quality project work compared to previous coursework developed independently. Our results encourage curricula development to foster interactions between landscape architecture and environmental engineering students.

Keywords: cross-disciplinary; collaborative learning; environmental engineering; landscape architecture; survey; undergraduate education.

Reference to this paper should be made as follows: Georgakakos, C.B., Cerra, J.F., Allred, S.B., Williams, K., Walter, M.T., LoGiudice, E. and Smith, G. (2026) ‘Cross-disciplinary learning in environmental engineering and landscape architecture’, *Int. J. Collaborative Engineering*, Vol. 2, No. 5, pp.1–35.

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This paper is a revised and expanded version of a presentation entitled 'Cross-disciplinary learning in environmental engineering and landscape architecture' presented at The American Geophysical Union Annual Meeting, San Francisco, CA, 9–13 December 2019.

1 Introduction

Landscape architecture (LA) and environmental engineering (EE) practitioners routinely collaborate professionally, yet they typically receive little formal opportunity to develop collaborative skills between their disciplines during academic training. These two career trajectories could mutually benefit from joint academic opportunities to understand, appreciate, and combine their respective skills. In this study, unique teaching and research opportunities were investigated by structuring collaboration between students in a LA urban design studio course and an EE watershed engineering course. Students engaged with three small municipalities to create alternative climate-adaptive stormwater and flooding designs. The primary objective of this study was to identify challenges and opportunities for codifying collaborative interactions into our respective curricula.

Some researchers suggest engineering education has lacked the professional preparation engineers require to succeed in the workplace. Mills and Treagust (2003) argue that engineering education has omitted realistic communication and teamwork skills needed to facilitate intra- and cross-discipline collaboration, stating that engineers often complete undergraduate education without developing these skills. To address this, Mills and Treagust (2003) suggest changes in engineering accreditation programs to develop interpersonal skills in addition to the traditionally emphasised technical skills. Tejedor et al. (2018) suggest that the type of engineer required to solve the complex problems of sustainability will need to co-create knowledge in ways the traditional curriculum does not instruct. Today, multidisciplinary collaboration and communication skills appear on the Accreditation Board for Engineering and Technology (ABET) (2017) criterion checklist for EE, although little research has been done to determine if the changes have been implemented effectively.

LA professional programs are similarly accredited by the Landscape Architecture Accreditation Board (LAAB). LAAB emphasises communication skills and the importance of engaging communities with the curriculum to "provide a source of service learning opportunities for students, scholarly development for faculty, and professional guidance and financial support" (LAAB, 2016). While LAAB does not explicitly discuss working across disciplines as a curricular requirement, LAAB does discuss community engagement and working with clients (LAAB, 2016), which featured prominently in this collaboration. Transdisciplinary action research is also described as distinct from multidisciplinary and interdisciplinary action research in the academic LA literature, consistent with the description provided by Stokols (2006) (e.g., Thering and Chanse, 2011; Stokols, 2011; Carlson et al., 2011).

Although collaboration can be complicated, through shared responsibilities, it may foster idea development and deeper achievement above and beyond an individual working alone. While collaboration comes in many different forms, this study focuses on cross-disciplinary, peer collaboration. Peer collaboration, as defined by Phelps and Damon (1989), describes students, starting with similar knowledge bases, working to solve the same problem. Our study adds complexity to this interaction by requiring cross-disciplinary collaboration amongst students with different disciplinary trainings. Our cross-disciplinary groups therefore approached projects with considerably different knowledge backgrounds, skills, and vocabularies. Though our study involved a significant stakeholder engagement component, student collaboration is the focus of this paper, as evaluated by the students and instructors.

1.1 Project-based service learning

This study centres on a service-learning design project involving peer collaboration between EE and LA students. Service learning is defined by Jacoby (2003) as experiential learning through which students address community needs, with reflection targeted at specific learning outcomes. This critical reflection is an important part of service-learning. Defined by Jacoby (2015), "critical reflection is the process of analyzing, reconsidering, and questioning one's experiences within a broad context of issues and content knowledge." While critical reflection is not typically a part of the engineering curriculum, service learning is better established in LA curricula, with critical reflection more likely practiced. However, methods for establishing critical reflection about engaged experiences vary widely and are dependent on the initiative and capacity of the instructor.

Hillman (1999) suggests service learning projects are most beneficial when all sides both aid and are aided by the other partner(s). Namely, there is no single recipient and no single provider; all partners fill both roles. To achieve this relationship, our approach strays from the commonly-followed path of volunteerism and community service and instead incorporates bidirectional defining of the project goals and design considerations.

Project-based learning develops student critical thinking and interest by engaging students in real world issues. Blumenfeld et al. (1991) set the following guidelines to achieve maximal interest in course projects:

1 tasks should be varied and include novel information

2 the problem itself has value aside from learning the material

3 the problem adequately challenges students

4 students generate final products to provide project closure

5 students choose their own solution path

6 students have the opportunity to work with others when designing paths forward.

Project-based learning gives students more control over the direction of their learning in the context of a societally important issue.

In assessing the effectiveness of project-based learning, Bilgin et al. (2015) found that project-based learning was positively received by students and allowed for deeper understanding. However, positive qualitative statements were often accompanied by negative obstacles to the learning process such as reduced teaching efficiency, differing positions of groups resulting from differing learning paths, lack of time and group structure, and difficulty implementing the new learning system. Certain impediments, such as undervaluing project-based learning in the context of tenure appointments and lack of project-based learning resource availability (Arnim Wiek et al., 2014), may discourage instructors from starting project-based learning initiatives. Some studies have shown that project-based learning may not impact all students equitably. Han et al. (2015) found that students who earned lower grades benefited more from incorporation of project-based learning into STEM courses than higher scoring students. Han et al. (2015) also found that those students who consistently were the lowest performers were from economically disadvantaged or at-risk backgrounds, non-native English speakers, and special needs students. Project-based learning may therefore be especially beneficial when applied in minority-majority classrooms.

1.2 Peer and cross-disciplinary collaboration

Peer and cross-disciplinary collaboration are two distinct forms of collaboration that may co-occur. Peer collaboration refers to interactions between students with similar educational backgrounds. Cross-disciplinary collaboration refers to interactions between students of differing academic disciplines.

Peer collaboration has been extensively used in classrooms. Lumpkin et al. (2015) overwhelmingly found that students positively perceived working in small peer groups. Students identified peer-peer learning and tackling more complex problems as peer collaboration benefits.

Cross-disciplinary collaboration involves similar challenges to peer collaboration, with the added complexity of peers approaching the same topic across departmental boundaries. Yet despite obstacles, cross-disciplinary collaboration allows unique pooling of expertise, instruments, funds, and knowledge to address problems difficult to address through single-discipline work (Rijnsoever and Hessels, 2011).

Initially, collaboration often requires generation of consistent and mutually understood terminology. Jeffrey (2003) found that establishing a common language significantly alleviates initial communication issues and delays stemming from crossing disciplines. Language consistencies are just one of several tools used to alleviate many cross-discipline issues. Jeffrey (2003) identified usage of metaphors, third-party conversation facilitators, and negotiation skills as tools leading to more successful collaborations. Pennington (2008) agreed that facilitators help direct conversations around potential obstacles and that generation of shared tools or resource can ease communication strains. Cummings and Kiesler (2005) suggest that direct supervision and face-to-face meetings streamline student training and generation of new ideas in cross-discipline research. In our study, facilitation was initiated by course instructors and teaching assistants (TAs) and largely continued independently by EE and LA student-groups.

Pennington (2008) suggests the problem solving cognitive structures within disciplines should be ‘tuned’ or ‘restructured’ to account for differing frameworks of each discipline. According to Pennington (2008), collaboration requires participants have a working understanding of others’ expertise. Because of framework restructuring, cross-disciplinary collaborations may take more time than anticipated. Jeffrey (2003) found that in working with a cross-disciplinary group of computer and social scientists, the largest obstacles encountered were inconsistent vocabularies and difficulty agreeing on data type prioritisation (i.e., qualitative versus quantitative data). Dewulf et al. (2007) argue researchers from different disciplines have unique ways of framing problems, collecting data, and analysing results, and that cross-discipline teams frame research problems differently than single-discipline studies. Dewulf et al. (2007) state the reason for these frame shifts are differences in the perceived project objectives, in part because collaborative groups define project boundaries differently. Although Dewulf et al. (2007) and Jeffrey (2003) analysed cross-disciplinary *research*, we anticipate these frame-shifts could also prove helpful in cross-disciplinary, project-based *learning*, especially among students with different professional training and backgrounds.

Collaboration does not come without pitfalls. Dewulf et al. (2007) found that few concepts are self-evident to all participants, project meetings can generate significant confusion, and different disciplines associate a unique hierarchy of importance to topics. Dewulf et al. (2007) identified actions that could alleviate cross-disciplinary issues such as acknowledging differences, generating new frames of reference, and exploring collaborators' ways of thinking. Pennington (2008) suggests that collaborative research should be initiated with collective thinking and establishment of frameworks. Similarly, Cummings and Kiesler (2005) warn collaborative research across multiple universities was negatively associated with generation of new ideas, knowledge, student training, and project outreach in comparison to research completed within a single university. To mitigate cross-discipline issues, Cheng and Leong (2017) propose the use of knowledge management ecology systems to aid cross disciplinary research, as has previously been done within disciplines. Cheng and Leong (2017) suggest the proposed path of knowledge creation, retrieval, transfer, and application to aid in cross disciplinary work. Though we recognise research across institutions varies significantly from learning across disciplines, several of the same obstacles may be present during cross-disciplinary learning.

To frame cross-disciplinary interactions, several types of cross-disciplinary relationships are described in the literature: multidisciplinary, interdisciplinary and transdisciplinary (e.g., Stember, 1991; Rosenfield, 1992; Aagaard-Hansen and Svedin, 2009; Kirk-Lawlor and Allred, 2017). Aagaard-Hansen and Svedin (2009), who in turn draws from Rosenfield, (1992), defines the relationships as:

> "Level one: multidisciplinary. Researchers work in parallel or sequentially from disciplinary-specific base to address a common problem. The total result of the research effort appears as the sum of the partial efforts with a low level of further integration.
>
> Level two: interdisciplinary. Researchers work jointly but still from disciplinary-specific basis in interactive modes of operation in order to address a common problem. Integration efforts are given care and interest but not to the extent that the 'input' competences have lost their specificities.
>
> Level three: transdisciplinary. Researchers work jointly using shared conceptual frame-works that are specifically designed for the purpose of a particular research endeavor and drawing together disciplinary-specific theories, concepts, and approaches to address a common problem."

Our study investigates collaboration between EE and LA from student, TA, research fellow, and faculty perspectives, while aspiring to push cross-disciplinary interactions between students toward higher-level interdisciplinary engagements. The student projects incorporate service learning, project-based learning, peer collaboration, and cross-disciplinary collaboration methods in the context of developing strategies to address current and projected flooding under climate change scenarios faced by municipalities.

2 Methods

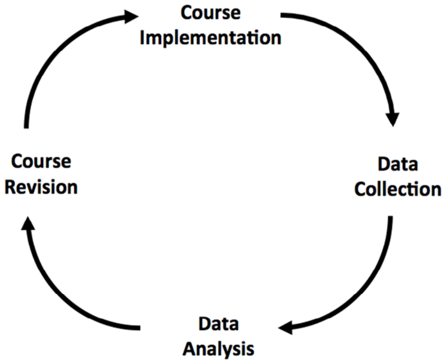
2.1 Class and student descriptions

This paper discusses the cross-disciplinary aspects of LA and EE student experiences resulting from cross-collaboration between two project-based learning courses. Both EE and LA courses were established courses within their disciplines. The LA course was an advanced urban design studio typically taken by seniors. While LA students learn technical design knowledge in other required coursework this climate adaptive design studio synthesises this knowledge. The studio links students with community members and technical experts for design projects. Because of the interdisciplinary nature of climate adaptation in practice, undergraduate students in planning (Bachelor of Arts in Urban and Regional Studies) were also invited to participate. All students enrolled in the LA course were analysed together and responses not separated by major.

The engineering course is an EE capstone design course, and is one of several required EE course options. This course has historically focused on flooding issues brought forth by community members, and therefore transitioned nicely with the LA course to centre on community-driven flooding adaptation. The EE course enrols 4th year EE and biological engineering undergraduate students; henceforth combined as EE students. Collaborative design project work was done outside of class in the latter half of the semester.

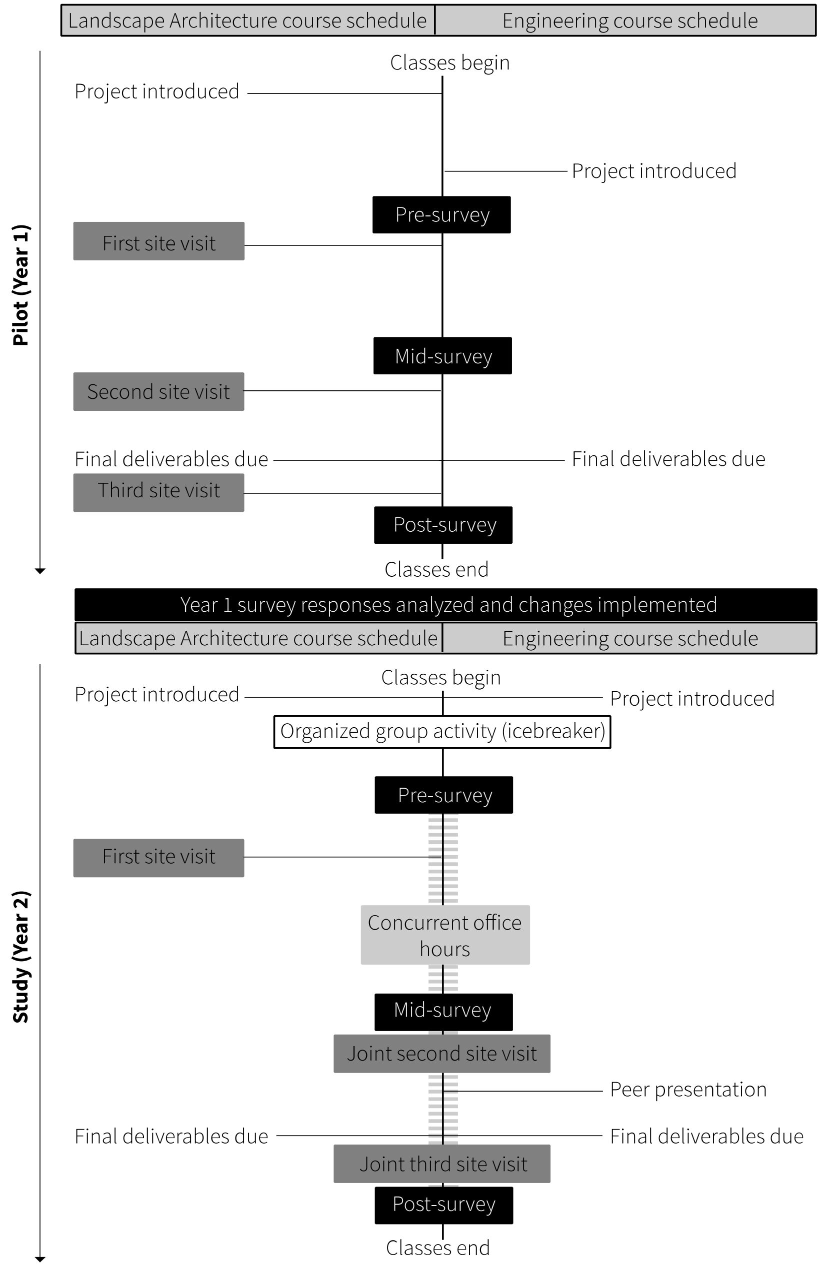
About half the EE class (15 of 33 students) collaborated with the LA class. Collaborative teams consisted of three EE with two to four LA and planning students. The other half of the EE class (18 of 33 students) worked in groups of 3 EE students and did not collaborate with the LA course. Student feedback from groups consisting only of engineers (EE-only groups) was compared with feedback from engineers collaborating with landscape architects ($\mathrm{EE}_{\mathrm{LA}}$ groups). All LA students were paired in collaborative teams. All groups were evaluated using the same methods, allowing the EE-only students to serve as a type of 'control' for this study to reflect on the relative effectiveness of cross-disciplinary interaction. The collaborating groups (LA-EE) and EE-only groups worked at different study sites and, as such, there were some natural differences between the collaborations beyond the disciplinary differences within groups.

Figure 1 Structure for incorporating data collected from students to improve the courses and LA-EE collaboration



Note: Specific course revisions and timeline of changes may be seen in Figure 2.

Figure 2 Course timelines during the pilot and study years



Notes: The EE timeline is on the right half and the LA timeline is on the left half of the figure. Items that appear on one side or the other were completed by the classes during normal class hours. Grey or white boxes crossing the middle of the figure indicate activities conducted jointly with both LA and EE students. Students shared workspaces outside of these timeframes, though they were not instructor planned and do not appear on this figure.

The collaboration between these courses is part of an ongoing, multiyear course relationship developed via an iterative and reflective process (Figure 1). Prior to the pilot year (see Figure 2 for course timelines), EE graduate students supported the LA studio by helping interpret existing and projected flood risks in participating communities. Based on these initial positive experiences, the LA and EE course instructors agreed to formally begin course collaboration the pilot year. EE graduate student consultation was available to all students of both courses all years. This paper primarily investigates the second iteration (study year) of the LA-EE collaboration, which incorporated adjustments suggested by the pilot year assessment.

LA-EE groups were charged with designing alternative climate adaptation strategies for a Hudson River Estuary municipality. The EE-only groups designed stormwater management systems for two different small communities impacted by recent flooding, one inland municipality in NY's Finger Lakes region and one municipality along Lake Ontario. For each of the three project sites, students were tasked to overcome design challenges that the instructors anticipated could not be easily addressed by a single disciplinary team. In this way, groups working at the same sites generated original non-overlapping solutions to the municipalities' issues.

All groups interacted with stakeholders; all students within the same class were given the same instructions and offered the same assistance. LA-EE groups presented their final designs to stakeholders at a community meeting while EE-only groups delivered electronic and hard copy reports to their stakeholders. Teaching faculty and staff arranged project site field trips for each group. LA-EE groups had three field trips/stakeholder meetings to gather ideas about the problems their community faced, receive feedback on preliminary ideas, and present final designs. LA-EE groups interacted with city officials, residents, and business owners during in-person meetings and remotely (e.g., conference calls, Skype). EE-only groups had one instructor-moderated site visit to observe locations with substantial flooding and meet with local government officials, town engineers, and residents. Several EE-only groups followed up with independent site visits and e-mail correspondence to gather additional information. A few EE-only groups primarily interacted with stakeholders via phone calls and e-mail. The EE TA held a minimum of two office hours per week to aid in project development. The LA-EE groups were encouraged to meet together during these office hours. All groups attended office hours several times.

The two classes are pedagogically very different. The LA studio had nine hours a week of in-person interaction with the instructors, with some lecture-style teaching but most time focused on interactive design instruction and student project collaboration. EE students participating with LA team members collaborated primarily outside course hours. The EE course is more traditional, with two hours/week of lecture and a three hours/week lab to analyse and design stormwater structures. EE students were expected to largely work outside of class on their capstone projects.

Guidelines for effective group collaboration were given to all groups near the beginning of the collaboration. These guidelines were followed up with informal in-class check-ins throughout the semester by the instructors and TAs.

2.2 Course adjustments

Based on pilot year feedback, we added more instructor-mediated events, greater opportunity for instructor involvement, more in-class discussion, and intermediate due dates to the engineering course. We began the process several weeks earlier in the study year to alleviate some cross-disciplinary stress students felt, as expressed in pilot year feedback.

To begin, students participated in three activities followed by an initial project planning meeting with design teams. The activities were chosen to increase communication and build a joint problem-solving language. The first activity focused on learning names and warming up for later activities. The second activity increased the level of communication required from one on one interactions to whole group discussion and simple problem solving. Students repeated the second activity several times to demonstrate that practice and communication can increase efficiency. The third and final activity required deeper problem solving and group thinking to solve a more complicated puzzle.

Implementing intermediate deadlines was intended to help students formulate ideas, spur discussion, and encourage early collaboration. Intermediate deadlines also allowed for more instructor involvement earlier in the idea generation process. In the study year, EE students were required to give early design idea presentations to the EE class to receive peer and instructor feedback. Leading up to these presentations, more students attended office hours and designs advanced more rapidly (TA reflections). During the study year we added two interim due dates and a warm-up assignment for the EE students. These added deliverables ensured students were familiar with their study site and had thought through and received feedback on calculations. This organisation reduced stress and helped organise student projects in comparison to the pilot year (TA reflections). The LA students had several effective interim due dates for their deliverables, which allowed for peer and instructor feedback both years.

More effective alignment of course schedules was another alteration recommended for future collaborative projects from the pilot and study years. Instructors also organised open office hours and studio time during which LA and EE students were invited to EE office hours and LA studio sessions respectively during the study year. These joint meetings were encouraged throughout the semester, though utilised primarily in the last third of the courses.

2.3 Group assignment

Instructors paired five EE teams with LA students to collaborate on their design project. Each LA group had two LA students with at least one urban planner. Six EE-only groups worked on two additional project sites, three groups per project site.

EE students ranked their preferred project site between the three design project sites, knowing that one project would involve LA-EE collaboration. Most EE students worked on their first choice, with a few given their second choice. The EE instructors used EE peer evaluations from previous EE assignments, independent of the design projects, to distribute EE students among groups. Specifically, students who were perceived as contributing above and below expectations were evenly distributed between groups. EE students with relevant skills (e.g., GIS, computer programming) were also distributed between groups. These measures created groups with complementary skill sets.

2.4 Data collection

Surveys were distributed before, during, and after student project engagement. These surveys use a mixed methods approach by including both open-response and Likert-style questions (surveys 1, 2, and 3 in Appendix B). A mixed approach of qualitative and quantitative data collection was chosen to better interpret the complexities of student cross-disciplinary experiences. The three surveys are hereafter referred to as pre-, mid-, and post-survey. Questions were written by the authors, which included the course instructors and TAs, and were exempted from full institutional review board review. All surveys were anonymous throughout the semester and therefore could neither be paired with later individual responses nor with final deliverables. Project site was the only identifier associated with each survey. Post-survey quantitative questions were based on validated questions developed to assess group effectiveness of cross-disciplinary students working on a collaborative project (Broussard et al., 2007). The standard set of questions measured synergistic knowledge development, working interdisciplinarily, task conflict and psychological safety of student cross-disciplinary groups (Broussard et al., 2007). Synergistic knowledge development is the process by which teams constructively integrate diverse perspectives of team members while task conflict is about effectively managing conflict that may arise from different viewpoints (Mu and Gnyawali, 2003; Broussard et al., 2007). Psychological safety is high when team members believe the group is a safe environment for varying views to be expressed (Mu and Gnyawali, 2003; Broussard et al., 2007).

EE final reports were used as a metric of effective group collaboration and idea generation. Reports were compared between EE-only and EE_{LA} groups. Student responses and deliverables were averaged across all groups working at the same study site. LA design products were not compared as there were no LA-only controls for comparison.

The TAs for both the EE and the LA courses recorded observations made during office hours, field trips, and in-class. These observations were used to facilitate discussion mid-semester and inform future collaboration. Faculty from both courses also generated post-collaboration reflections.

2.5 Data analysis

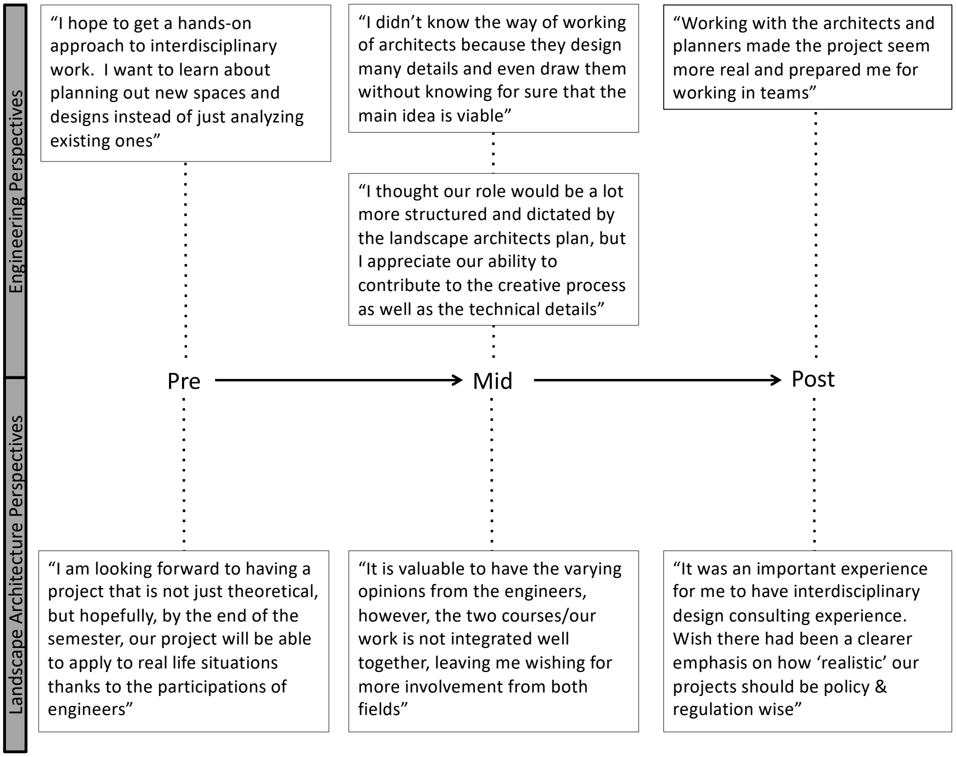
Open-ended questions and written observations were coded for themes. All primary analysis was completed by the TAs. Likert-style questions were analysed using R-Studio and tested for normality using the Shapiro-Wilkes normality test. Upon conclusion that some questions of all groups were not normally distributed, a Wilcox rank sum test was performed to determine statistical difference between groups for each Likert style question. Wilcox rank sum was also used to determine statistical difference between engineering final report grades.

Principal components factor analysis with varimax rotation was conducted using SPSS on survey question items measuring the constructs of synergistic knowledge development, working interdisciplinarily, and psychological safety as outlined by Broussard et al. (2007) (survey 3 in Appendix B). Factor analysis is a data reduction technique that allows researchers to analyse the underlying dimensions of various factors. The completed factor scales used Cronbach's alpha as an estimate of reliability/ consistency. An alpha value greater than 0.8 suggests good-excellent reliability between groups while a value lower than 0.7 suggests the groups may not have internal consistencies (Cortina, 1993; Taber, 2018; van Griethuijsen et al., 2015). Summative scales were created for each factor. Descriptive statistics for the individual questions and results from the factor scales are presented. ANOVA’s were used to compare mean values between groups (EE_{LA}, LA, and EE-only). The significance level was set at $p < 0.05$.

3 Results

Our results show differences between LA and EE_{LA} (EE students engaged in LA-EE collaborations) and EE-only groups. Quantitative and qualitative responses to questions in the three surveys are provided below (quantitative responses also in Appendix A, Survey 2 and Survey 3). Sample sizes are the number of students in each group who responded to each survey question. Figure 3 demonstrates student perspective changes over time.

Figure 3 Student perspectives of interdisciplinary collaboration



“I hope to get a hands-on approach to interdisciplinary work. I want to learn about planning out new spaces and designs instead of just analyzing existing ones”

“I didn’t know the way of working of architects because they design many details and even draw them without knowing for sure that the main idea is viable”

“I thought our role would be a lot more structured and dictated by the landscape architects plan, but I appreciate our ability to contribute to the creative process as well as the technical details”

“Working with the architects and planners made the project seem more real and prepared me for working in teams”

“I am looking forward to having a project that is not just theoretical, but hopefully, by the end of the semester, our project will be able to apply to real life situations thanks to the participations of engineers”

“It is valuable to have the varying opinions from the engineers, however, the two courses/our work is not integrated well together, leaving me wishing for more involvement from both fields”

“It was an important experience for me to have interdisciplinary design consulting experience. Wish there had been a clearer emphasis on how ‘realistic’ our projects should be policy & regulation wise”

Notes: Comments were in response to open-ended survey questions on pre-, mid-, and post-surveys. EE_{LA} quotations appear on the top of the figure while LA quotations appear on the bottom.

3.1 Pre-collaboration survey

Eight open-ended questions were asked in the pre-survey.

3.1.1 Qualitative survey results

Across all groups, students were excited to engage in what they saw as 'real-world projects' during interdisciplinary collaboration. On pre-collaboration surveys (survey 1, Appendix B), one LA student stated "hopefully, by the end of the semester, our project will be able to apply to real life situations thanks to the participations of engineers" (question 1, pre-survey). An $\mathrm{EE}_{\mathrm{LA}}$ student stated "I hope to get a hands-on approach to interdisciplinary work. I want to learn about planning out new spaces and designs instead of just analyzing existing ones." Site and landscape-scale design are central to the LA curriculum, while often absent in EE coursework. EE-only students focused on project-based learning rather than collaboration in their responses. For example one EE-only student stated "I'm hoping to learn more about the real-world application of what we learn in class [...]."

Students were asked to identify difficulties they envisioned during these projects (question 4, pre-survey). Most obstacles perceived by EEs centred on group dynamics issues within EE-only and LA-EE groups alike. However, some EE students also identified a few project-based learning obstacles such as gathering information rather than being provided information (an $\mathrm{EE}_{\mathrm{LA}}$ student), realistic budgetary constraints of a project that is implementable (an EE-only student), delving into topics not discussed in the courses thus far (an EE-only student). Most LA students commented on potential collaboration obstacles such as shared languages, differing value systems, and unique ways of working, while a few also commented on course logistics, difficulty tackling such a technical problem, and persuading stakeholders of their work's value. One LA student expressed concern about differing project practicality opinions. Students were asked to identify methods of overcoming those obstacles (question 5, pre-survey). Almost all proposed solutions involved improvement of group dynamics and communication and avoided project-centred solutions. One EE-only student mentioned asking instructors for advice as a solution. LA students similarly identified communication, compromise, and maintaining an open mind as solutions to their perceived issues. Anecdotally, the engineering TA noted, as the semester progressed, that project-based learning obstacles dominated her conversations with students rather than the anticipated possible group dynamics issues previously identified.

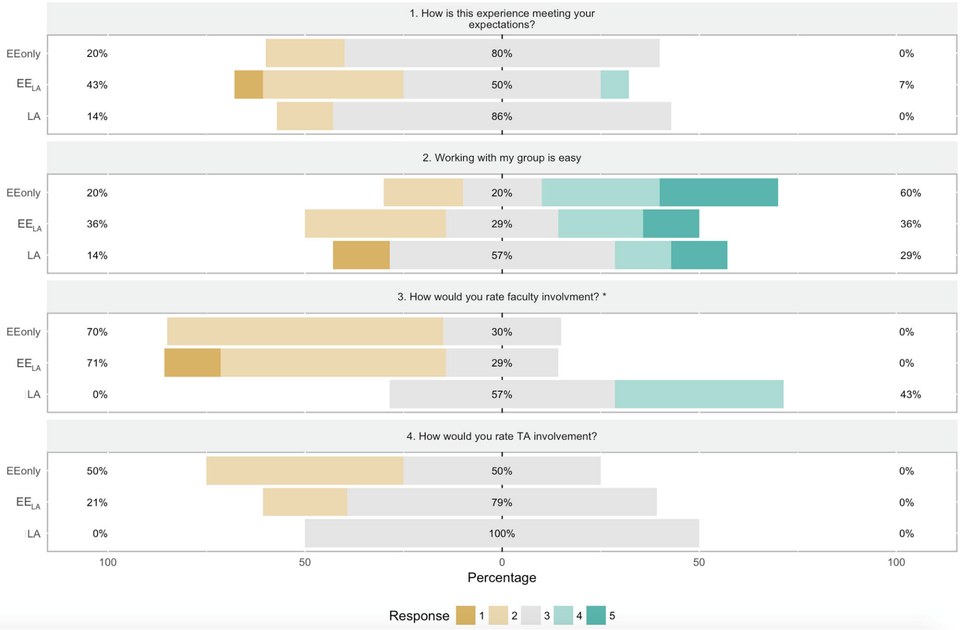
3.2 Mid-collaboration survey

Four Likert style questions (with room for comment) and five open-ended questions were asked in the mid-survey. Five engineering student surveys are not included due to inability to distinguish project group ($\mathrm{EE}_{\mathrm{LA}}$ vs. EE-only).

3.2.1 Quantitative survey results

Mid-survey response distributions are given in Figure 4 (questions provided in survey 2, Appendix B). All groups indicated their experiences were meeting expectations (question 1, mid-survey) (1 = ‘extremely short of expectations’ and 5 = ‘exceeds expectations’), with no groups statistically different from one another (p-values > 0.05).

Figure 4 Mid-collaboration survey Likert scale responses (see online version for colours)



Notes: The scales for each of these questions differ. In order from top to bottom, the scales are 1 – far short of expectations, 5 – far exceeded my expectations; 1 – extremely difficult, 5 – extremely easy; 1 – far too little, 5 – much too much; 1 – far too little, 5 – much too much. An ‘*’ marks statistical difference between LA responses and EE$_{\text{LA}}$ responses in question 3 (p = 0.016).

When asked to rank sufficiency of faculty involvement (question 3, mid-survey), EE$_{\text{LA}}$ and EE-only groups showed no statistical difference, and both EE groups indicated a need for more faculty involvement in comparison with LA students (p-value = 0.003). Mean responses for all groups were 3.43, 2.14,and 2.30 with standard deviations of 0.53, 0.66, and 0.48, for LA, EE$_{\text{LA}}$, and EE-only students, respectively (1 = ‘insufficient involvement’ and 5 = ‘too much involvement’). These results reflect that the two courses had different amounts of faculty involvement in direct project help; the LA studio met nine hours/week with instructors to specifically work on the project throughout the semester while the EE course met fewer hours/week, with the project serving as an essentially out-of-class assignment. No groups showed a statistical difference in sufficiency of TA involvement (question 4, mid-survey) (1 = ‘insufficient faculty involvement’ and 5 = ‘too much faculty involvement’).

When asked is ‘working with my group is easy?’ (question 2), we found no statistical differences between groups (p-value > 0.05) (1 = scale of ‘strongly disagree’ and 5 = ‘strongly agree’).

3.2.2 Qualitative survey results

Mid-collaboration students began highlighting some of the difficulties of the collaborative environment. An EE student stated "[t]he biggest difficulty has been communicating with each other and the landscape architects to stay on the same page", (question 8, mid-survey). Though, this sentiment was not expressed by all groups. An EE_{LA} student reflected in the same survey, "we're good at communicating with each other so just having that open communication where we can express our concerns and work as a team to find a solution has been great." A LA student responded to the same question stating that "the engineers are receptive to our ideas but have not contributed much", highlighting that the communication strain noted by engineers may have manifested itself into unequal work sharing.

In the mid-collaboration surveys when asked to describe how their groups had been collaborating, EEs stated a desire for more involvement and influence on the outcome of the designs, and LAs similarly stated they had envisioned EEs being more involved than they were (question 9, mid-survey). Both groups recognised the collaborative effort could be enhanced through proposed solutions to obstacles (question 8 responses), but little evidence is seen in the surveys that behaviour changed after this recognition. LA students tended to identify scheduling issues, while EE_{LA} students cited communication between disciplines, and lack of direction from LA students as obstacles. To accommodate scheduling issues, the EE class devoted more lab time to discussing final projects, and resent guidelines to group collaboration to the class. However, post-collaboration survey open-ended responses suggest these obstacles were never entirely overcome. Both LA and EE_{LA} groups identify issues with their collaborators, as might be expected in an 'us vs. them' scenario. This mentality also persisted through the post-collaboration surveys.

3.3 Post-collaboration survey

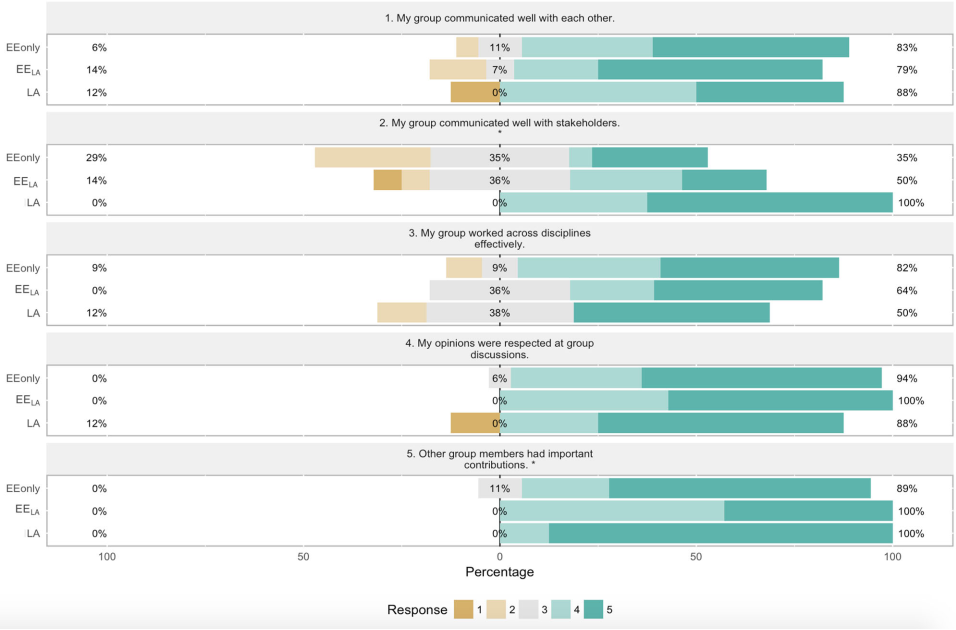
The final survey (survey 3, Appendix B) had six questions with quantitative, Likert-style responses, with opportunities for written elaborations, and three qualitative questions seeking text responses. These were followed by a battery of interdisciplinary learning evaluation questions like that referenced above by Broussard et al. (2007). As in Broussard et al. (2007), the synergistic dynamics, interdisciplinary work, task conflict, and psychological safety factors sections had three, five, three and four questions respectively.

3.3.1 Quantitative survey results

General quantitative student responses to the collaborative group learning component of this study were asked through five questions (Figure 5). All students on average agreed that "my group communicated well with each other" (question 1, post-survey), with no statistical difference between group responses (p-value > 0.05). All groups on average agreed that they worked well across disciplines (question 3, post-survey), with no statistical difference between groups (p-values > 0.05). When asked to evaluate the importance of contributions by other group members, LAs significantly differed from EEs (question 5, post-survey) (p-value = 0.050), with LAs rating their group members with a mean of 4.88 while EE_{LA} student rated the same question with a mean of 4.43.

The EE-only groups did not differ from either of the collaborating groups with means of 4.55 each (p-value = 0.35 for comparison with EEs; p-value = 0.27 for comparison with LAs).

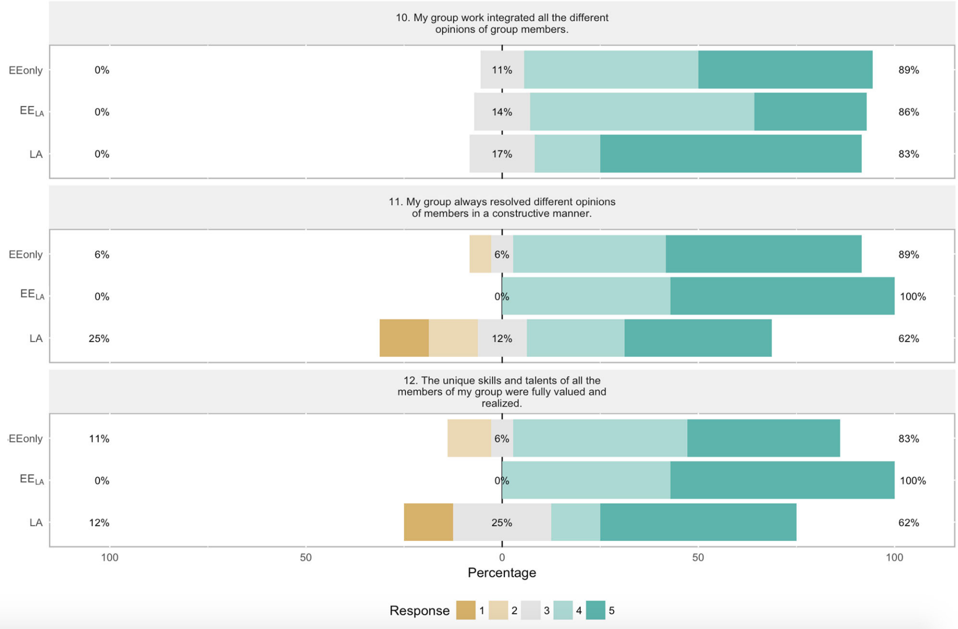
Figure 5 General group collaboration questions and response distributions from post-collaboration survey (survey 3, Appendix B) (see online version for colours)



Notes: Responses are normalised to percentage of total responses in each group category. Percent positive, neutral, and negative responses are shown on the right, centre and left of each row respectively. Students used a Likert scale of 1 – strongly disagree, 2 – disagree, 3 – neutral, 4 – agree, 5 – strongly agree to rank their responses. An '*' marks statistical difference between LA responses from EE_{LA} student responses in questions 2 and 5 (p = 0.0182 and 0.0498 respectively).

Synergistic knowledge development was analysed through three questions (Figure 6). Each post-survey question was ranked using the Likert scale of 1 – strongly disagree, 2 – disagree, 3 – neutral, 4 – agree and 5 – strongly agree. When asked about group dynamics, all groups positively ranked the statements "my group work integrated all the different opinions of group members" (question 10, post-survey), "my group always responded to different opinions of members in a constructive manner" (question 11, post-survey), and "the unique skills and talents of all the members of my group were fully valued and realized" (question 12, post-survey). All groups felt their opinions were respected at group discussion (question 4, post-survey). No synergistic knowledge development questions showed statistical difference between groups (p-values > 0.05). These responses suggest that groups, in general, created working environments that were inclusive to individual involvement. The synergistic knowledge development factor analysis and Cronbach alpha value of 0.849 suggests a highly reliable scale. All groups rated the experience highly (approximately 4.0 on a 5.0 scale), with no statistical difference between groups (see Table 1 in Appendix A). These ratings demonstrate that all students were able to achieve synergistic knowledge development within their project groups.

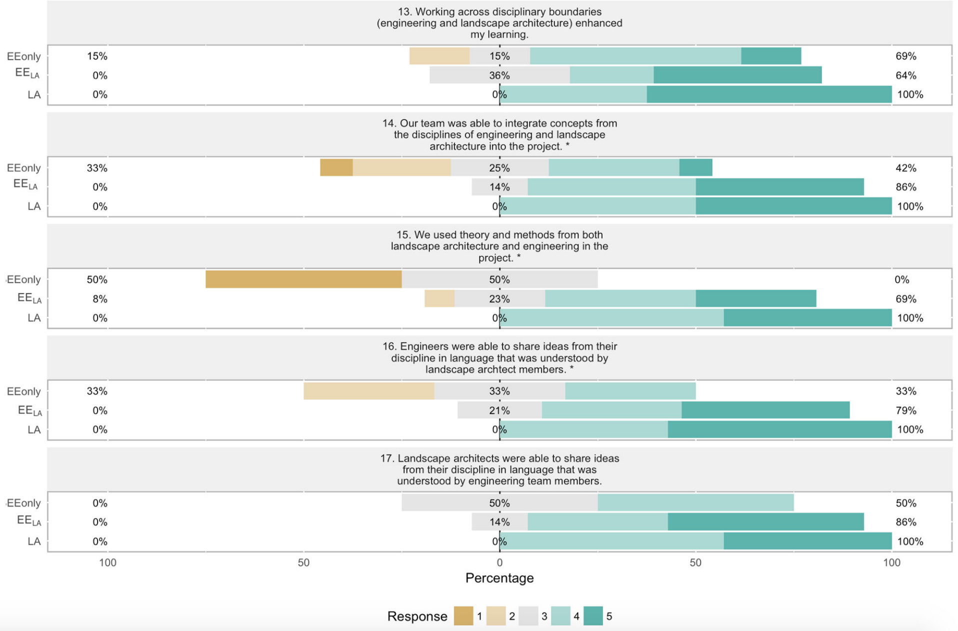
Figure 6 Synergistic knowledge development questions and response distributions from post-collaboration survey (survey 3, Appendix B) (see online version for colours)



Notes: Responses are normalised to percentage of total responses in each group category. Percent positive, neutral, and negative responses are shown on the right, centre and left of each row respectively. Students used a Likert scale of 1 – strongly disagree, 2 – disagree, 3 – neutral, 4 – agree, 5 – strongly agree to rank their responses. There was no statistical difference between responses.

Working interdisciplinarily was assessed through five questions (Figure 7). When asked to rank the question "working across disciplinary boundaries (engineering and LA) enhanced my learning" (question 13, post-survey), all groups agreed that learning was enhanced, with no statistical differences (p-value > 0.05) observed between any group. Instructors were initially concerned about non-shared vocabularies between LA and EE$_{LA}$ students. Students were asked if "engineers were able to share ideas from their discipline in language that was understood by landscape architect team members" (question 16, post-survey) and *vice versa* (question 17, post-survey). Both questions showed no statistical difference between LA and EE$_{LA}$ responses. Both groups ranked the ability of each group to present information across disciplines positively with average scores greater than 3. However, each group rated their own group higher on the Likert scale for effectively presenting information, though the difference is not statistically significant (p-value > 0.05). Students were asked to rate the statements "our team was able to integrate concepts from the disciplines of engineering and LA into the project" (question 14), and "we used theory and methods from both LA and engineering into the project" (question 15). Neither question showed statistical difference (p-value > 0.05) and both groups positively rated each question. Working interdisciplinarily factor analysis and Cronbach alpha value of 0.870 suggests a highly reliable scale. All groups rated the experience highly (greater than 4.0 on a 5.0 scale for collaborating groups), with no statistical difference between groups (see Table 1 in Appendix A). These scores demonstrate students perceived effective interdisciplinary collaboration regardless of discipline. EE-only students tended to not answer many of the working interdisciplinarily questions as they were less relevant to their projects, reducing the sample size of these questions.

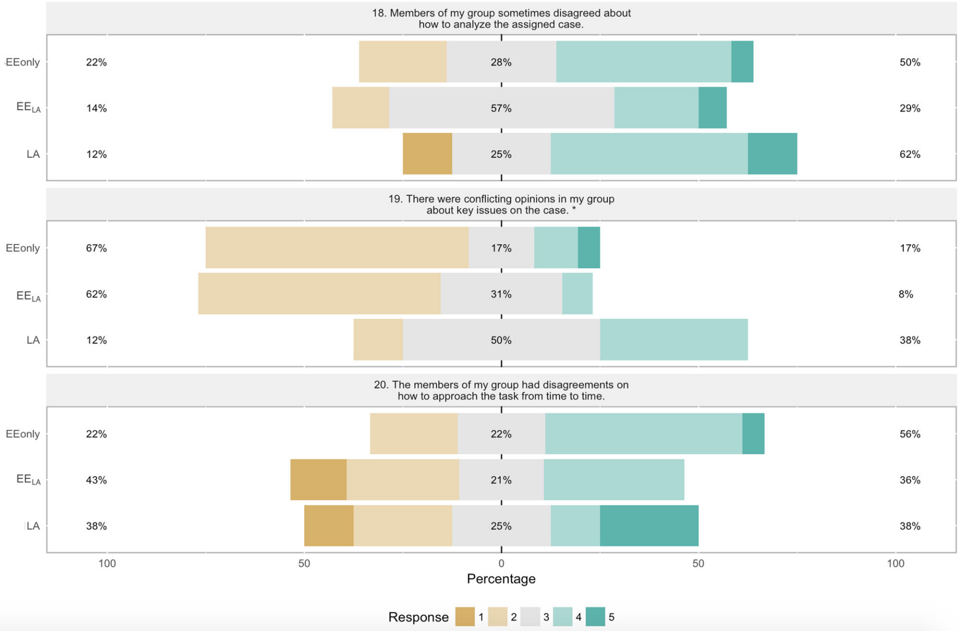
Figure 7 Working interdisciplinarily questions from post-collaboration survey (survey 3, Appendix B) (see online version for colours)



Notes: Responses are normalised to percentage of total responses in each group category. Percent positive, neutral, and negative responses are shown on the right, centre and left of each row respectively. Students used a Likert scale of 1 – strongly disagree, 2 – disagree, 3 – neutral, 4 – agree, 5 – strongly agree to rank their responses. An '*' marks statistical difference between EE$_{LA}$ and EE-only groups in question 14 ($p = 0.0078$) and LA + EE$_{LA}$ groups compared with EE-only groups in questions 14, 15, and 16 ($p = 0.0028$, 0.0401, and 0.0354 respectively).

Task conflict was analysed through three questions (Figure 8). Students ranked the statement "members of my group sometimes disagreed about how to analyze the assigned case" (question 18, post-survey). The two sets of groups comprising EE-only groups differed statistically (p-value < 0.05) in their responses to this question, but we do not have data to explain this difference. When asked to rank "if there were conflicting ideas about key issues in the case" (question 19), LA students suggested this was more of an issue than the EE students (p-value = 0.0236) (Figure 8). The mean response for LA, EE$_{LA}$, and EE-only were 3.25, 2.46, and 2.56, respectively (SD = 0.71, 0.66, and 0.92, respectively). When asked if "the members of my group had disagreements on how to approach the task from time to time" LA, EE$_{LA}$, and EE-only responses did not statistically differ. The two groups comprising EE-only students differed statistically in their response to this question (p-value = 0.028), but we do not have data to explain this difference.

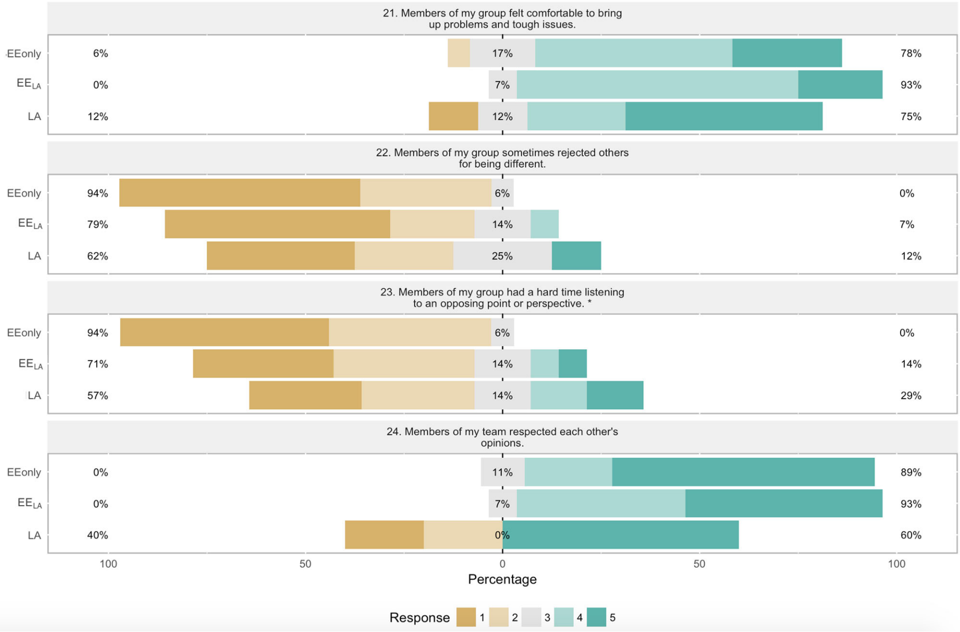
Figure 8 Task conflict Likert questions and response distributions from post-collaboration survey (survey 3, Appendix B) (see online version for colours)



Notes: Responses are normalised to percentage of total responses in each group. Percent positive, neutral, and negative responses are shown on the right, centre and left of each row respectively. Students used a likert scale of 1 – strongly disagree, 2 – disagree, 3 – neutral, 4 – agree, 5 – strongly agree to rank their responses. An ‘*’ marks statistical difference between LA and EE_{LA} student responses in question 19 (p = 0.0236).

Team psychological safety was analysed through four questions (Figure 9). When ranking whether “members of my group had a hard time listening to an opposing point or perspective” (question 23), LA students statistically differed from EE-only students (p-value = 0.039); and EE_{LA} and LA students in LA-EE groups (i.e., LA and EE_{LA} lumped) differed from EE-only students (p-value = 0.047). Mean responses from LA, EE_{LA}, and EE-only were 2.69, 2.14, and 1.53, respectively (SD = 1.44, 1.23, and 0.62, respectively). This suggests that the LA and EE_{LA} students had a more difficult time working through design changes/suggestions than EE-only students. This response is directly contrary to how students responded to “working with my group is easy” (question 2, mid-survey). All students perceived group members felt comfortable bringing up issues (question 21, post-survey), with no statistical difference between any groups (all p-values > 0.05) (1 = ‘extremely uncomfortable’ and 5 = ‘extremely comfortable’). All groups disagreed with the perception that anyone was treated differently because of personal differences (question 22, post-survey) with no statistical difference between groups. Similarly, all groups agreed or strongly agreed that “members of my team respected each other’s opinions” (question 24, post-survey), with no statistical difference among groups (all p-values > 0.05) (1 = ‘strongly disagree’ and 5 = ‘strongly agree’ for both questions 22 and 24, post-survey) (Figure 9). The psychological safety factor Cronbach’s alpha value of 0.649 suggests acceptable reliability of the scale (Cronbach alpha > 0.6), but the lower rating associated with the score (less than 4.0 on the 5.0 scale) suggests that students struggled with several group processes.

Figure 9 Psychological safety questions and response distributions from post-collaboration survey (survey 3, Appendix B) (see online version for colours)



Notes: Responses are normalised to percentage of total responses in each group category. Percent positive, neutral, and negative responses are shown on the right, centre and left of each row respectively. Students used a Likert scale of 1 – strongly disagree, 2 – disagree, 3 – neutral, 4 – agree, 5 – strongly agree to rank their responses. An ‘*’ marks statistical difference between LA & EE$_{LA}$ lumped groups compared with EE-only groups in question 23 (p = 0.0468).

3.3.2 Qualitative survey results

Students cited communication as something that went smoothly and that could be improved (questions 7 and 8, post-survey). It appears some groups communicated well within and among disciplines, while others struggled to identify effective communication methods. One EE$_{LA}$ student reflected that a benefit was “the different skill sets, experiences, and mindsets that each person brought to the team. We constantly impressed each other and volunteered to pursue different things in novel ways that we had some expertise or interest in learning” (question 10, post-survey). Another EE$_{LA}$ student stated “I think brainstorming was productive. We communicated well and worked out solutions to the problems [...] faced while keeping the stakeholders’ interests in mind. Each of our meetings were also very productive, since we got a chance to give feedback on each other's work and keep the same vision in mind" (question 7, post-survey). Conversely, a third EE_{LA} student stated, "we communicated TERRIBLY. There was little to no expectation set at the beginning of the project for a timeline or a framework for communication or sharing of information. This was, admittedly, due to some procrastination on our part [...] The greatest change was needed in file sharing" (question 8, post-survey). These varied perspectives suggest that group dynamics were either group specific, or may vary between members of the same group.

The collaboration had both beneficial and challenging student outcomes. One EE_{LA} student described the collaborative learning experience as "sort of [enriching]. The architects changed a lot of their ideas very frequently and it became difficult to collaborate", (question 6, post-survey) but in the next question response the same student stated "I enjoyed learning about how the architects approached similar problems to us in a different manner" (question 7, post-survey). A LA student reflected that the collaboration "opened my eyes to certain technical aspects of the reality of the interventions that I wouldn't have thought about otherwise" (question 6, post-survey). Both responses suggest the collaboration had beneficial learning outcomes by broadening student perspectives.

However, this positive reflection was not the only perspective represented by LA or EE students. One LA student reflected "it was a good experience to work on a real project and engage with stakeholders. On paper, cross disciplinary classes sound great but this did not work out very smoothly. Expectations [...] were not clearly defined at the beginning [...] Timelines for eng[ineering] and LA were not well aligned" (question 8, post-survey). EE_{LA}s were similarly frustrated by timelines and lack of collaboration structure. Both EE_{LA}s and LAs separated challenges into an 'us vs. them' paradigm. Students suggested they had learned to work cross-discipline or within their group, despite obstacles such as departmental boundaries or non-contributing group members. These comments suggest opportunities to improve cross-course collaboration in future course iterations.

All LA-EE students agreed that the collaboration enhanced learning. Several EE_{LA} students claimed "by discussing and exploring ideas together, I gained a wider perspective from [the LAs'] view of expertise and it enriched our collaboration" (question 6, post-survey). An EE-only student thought "collaboration with another department should be imperative to all […] final projects, planning and development of solutions to watershed concerns are practically always rather interdisciplinary" (question 6, post-survey).

These positive remarks did not come without obstacles. One EE student stated "[i]t was exasperating for much of it, but at the end I left feeling excited, accomplished, and that I learned something and created something" (question 10, post-survey).

3.4 Engineering final deliverable analysis

The EE final deliverables were compared between EE_{LA} and EE-only groups. The largest differentiating theme that emerged was discussion of social implications and alternative uses of stormwater routing structures. Four of the five EE_{LA} groups mentioned social uses of stormwater routing structures such as community parks, garden beautification projects, walkways and floodable structures, while 1 of 6 EE-only groups mentioned alternative usages (increased habitat for recreational fishing). The human dimension of the LA ideas were discussed and presented as positive aspects of the work by EE_{LA} teams while

EE-only students were more likely to mention biological implications of their work. Within each project site there was also large variability between groups. One potential cause of that variability is discussed below concerning attendance of joint office hours.

The rubric used to grade EE reports can be found in Appendix C (Table 2). There was no statistical difference between scores earned by EE_{LA} and EE-only groups (p-value = 0.575), likely because the engineering rubric did not value non-engineering site design aspects in awarding points. The EE reports across the board were of similar quality, although emphasis on combined-use structures and other design choices incorporating social and cultural importance was, in large part, absent from the EE-only reports.

3.5 Course reflections

Joint office hours were non-uniformly attended across groups. Some groups chose to use the time to work collaboratively consistently from week to week while others chose to work outside of the designated instructor-mediated time. Instructors anecdotally noted that those groups present for more joint office hours appeared less anxious toward the end of the project and were given significantly more feedback than those groups who chose to work outside of this time. No specific data were recorded as to number of joint office hour attendances for each group. Those groups who attended joint office hours seemed to generate their common language and collaborative habits more easily than those groups who did not utilise this time (TA reflections). Groups that did not come as consistently to joint events seemed to rely more heavily on instructor mediated events to overcome collaborative obstacles, resulting in less holistic approaches to the project (TA reflections).

4 Discussion

4.1 Perspectives of cross-disciplinary collaborative learning experiences

Looking across surveys, we found student perspectives on the nature of the collaboration shifted as work progressed. Figure 3 outlines some of the key qualitative perspectives highlighted by students over the course of their cross-disciplinary interaction. Overall, students in EE_{LA} and LA groups began the collaboration feeling excited and hopeful to design projects differently than in prior learning environments. Mid-collaboration, responses became somewhat more mixed. While the majority of both LA and EE_{LA} students ranked working with their group positively (average >3, mid survey, question 2), the range of qualitative survey entries indicate challenges for some groups. This could be related to group chemistry and dynamics, the reality of project work setting in, or both. Mid-project is a stress inducing time regardless of collaborative environment, and frustration expressed by students does not necessarily suggest the cross-disciplinary collaborative environment is the cause of this frustration. However, at the end of the project LA and EE_{LA} groups seemed satisfied with their cross-disciplinary experiences, indicating that their group communicated well with one another (question 1, post-survey) and that their group worked well across disciplines (question 3, post-survey). Though not explicitly tested, its possible that the critical reflection induced by the surveys during cross-course effort may have aided the students in overcoming difficulties throughout the semester. The surveys may have refocused student attention on the collaborative effort, allowing their reflections to improve and inform their later actions. These check-ins also provided instructors with valuable insights so that mid-course adjustments could be made.

It also appears there was a discrepancy between what students expected and what they were required to do. EE students appear to have expected much more defined roles in the collaboration and more defined problems to solve. This cognitive dissonance, the gap between what students expect and what they experience, appears to have impeded the collaborative effort. The sooner students understood the open-endedness of the problem definition and initiated conversations with their collaborators, the smoother the projects progressed. Groups required differing amounts of time to overcome the paralysis that sometimes resulted from this cognitive dissonance, but those groups able to address these issues sooner appeared to collaborate more effectively than those who did not. The issue of cognitive dissonance, though not directly addressed in the study, is worthy of further investigation in the field of collaborative teaching.

While most students as a whole reflected positively on their cross-disciplinary experience post-collaboration, we do see a range of experiences in post-survey student reflections. The range of experiences, particularly with group communication and dynamics challenges in the LA groups, may be due to LA group composition; with groups of both LA and urban and regional studies (URS) students. Some URS students in the study year were enrolled with limited site design or graphic design background. While their planning skills were still relevant, the nature of their ability to participate in site design and representation efforts was more difficult. Instructors observed LA team challenges that may have been accentuated by these different technical capabilities, influencing their collaborative experience. In future studios, we will reinstate the design experience requirement to avoid introducing this factor into team dynamics.

4.2 Facilitating peer and cross-disciplinary collaboration in the university setting

Collaborative learning requires more instructor involvement than non-collaborative courses. While we generally observed that most groups overcame group dynamic obstacles associated with interdisciplinary learning, significant instructor involvement and orchestration was often necessary. Instructor mediated events appeared to positively encourage interactions between students, but proved difficult to coordinate. However, the authors believe that the instructors' effort is worth the enhanced student learning that accompanies cross-disciplinary efforts, and that the added cross-departmental collaboration challenges did not inhibit achievement of other student learning outcomes. It's also notable that LA, EE_{LA}, and EE-only students saw the collaborative experience as both positive and challenging alike.

When comparing the Cronbach alpha values between synergistic knowledge development, working interdisciplinarily, and psychological safety, it is important to recognise that students appear to have been somewhat uncomfortable being placed into interdisciplinary groups, evidenced by their lower psychological safety ratings, but that despite the vulnerabilities they felt, they self-reported positive synergistic knowledge development and working interdisciplinarily scores. It is therefore important to minimise the vulnerabilities students feel during collaborative projects to encourage beneficial student experiences.

4.3 Future opportunities to enhance cross-disciplinary collaboration

As tested in this study, survey responses were averaged across groups working on the same study site to provide insights about collaborative environments. A possible improvement to enhance tracking could be for survey identifiers to be matched with final projects. Then, group dynamics could be traced through the project timeline compared against final project work outcomes. More direct comparisons between cross-disciplinary and peer collaboration could also be made if all groups worked on the same study site with some in cross-disciplinary settings and others not. Nonetheless, despite these possible limitations, the qualitative data provided deeper insights into the inner-workings of groups.

In addition to introducing new communication technologies to facilitate collaboration, providing more structured cross-disciplinary exercises and ‘check-ins’ in class as well as openly discussing differences in vocabulary between disciplines on related topics could also enhance the cross-disciplinary experience. Many instructors have analysed tools to encourage peer collaboration and ameliorate obstacles encountered. The use of laptops and other online group document sharing aids has significantly enhancing group collaboration (Nicol and MacLeod, 2005), especially today when such tools are ubiquitous, allowing multiple, distant collaborators to work on the same documents. Communication in the media-savvy Generation Y, born 1980–1994 (Kennedy et al., 2006), and Generation Z, born 1995–2005, has become easier, with numerous communication avenues coming rapidly online. Kennedy et al. (2006) suggest it is now instructors who lack understanding of available communication corridors. However, Kennedy et al. (2006) demonstrate despite students’ increased availability of communication methods, communication still challenges students in group work.

5 Conclusions

In inviting cross-disciplinary interaction, we hope students learn to define and apply their own skills, value the skills of others, work across disciplines, and benefit from critical reflection. Cross-disciplinary service-based collaborative learning can be rewarding and exciting for students, instructors, and stakeholders by incorporating teamwork, group organisation and collaboration, interpersonal problem solving and other experiences into the learning process. However project-based learning, peer collaboration and cross-disciplinary collaboration each present challenges that are important to acknowledge before beginning. The authors believe cross-disciplinary collaboration has the potential to improve the quality of student learning by fostering skills in interdisciplinary collaboration that will be valuable during their professional careers upon graduation.

Acknowledgements

We would like to thank the Office of Engagement Initiatives at Cornell, and Cornell’s Center for Teaching Innovation for funding the interdisciplinary collaboration and analysis portion of this project, and the New York State Water Resources Institute for their ongoing support for the Climate-adaptive Design studio. We would also like to thank Eugene Law and Leslie Blythe for their review of this manuscript and Elizabeth Fabis for her assistance with figure generation. We appreciate the time and thought all community stakeholders put into meeting with students and discussing solutions to their stormwater and tidal flooding issues. We would also like to thank all students in both courses for the effort and time they put into their projects.

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Appendix A

Synergistic knowledge evaluation

Table 1 Factor analysis scales with means, standard deviations, and Cronbach's alpha values

	LA-students mean (SD)	*EE_{LA} students mean (SD)*	*EE-only students mean (SD)*	*Cronbach's alpha for factor scale*	*F-statistic (p-value)*
Synergistic knowledge development	3.92 (1.23) n = 8	4.43 (0.422) n = 14	4.26 (0.737) n = 18	0.849	1.13 (0.339)
Working interdisciplinarily	4.57 (0.497) n = 6	4.12 (0.641) n = 13	3.40 (n/a) n = 2	0.870	2.093 (0.154)
Psychological safety	3.20 (1.19) n = 7	3.20 (0.451) n = 14	3.58 (0.650) n = 17	0.649	1.628 (0.211)

Notes: 'n' refers to the number of responses used in the analysis. Sample sizes vary depending on number of students within each group, and who were present during in class surveying. EE-only students tended to not answer questions related to working interdisciplinarily, reducing their sample number substantially.

Appendix B

Survey questionnaires

Survey 1

Pre-collaboration survey given to all students just after design project introductions.

1 What do you hope to learn from this collaboration?
2 Do you think this collaboration will help prepare you for future interdisciplinary work between landscape architects and engineers?
3 How do you think this interaction will go?
4 What perceived difficulties might you need to overcome?
5 How might you overcome those difficulties?
6 What are you looking forward to in this collaboration?
7 What do you think you will be able to contribute to the collaboration based on your background?
8 What does it mean to you to be a good group member?

Survey 2

Mid-collaboration survey given to all students after initial site visits. For quantitative questions, an item analysis including mean (μ), standard deviation (σ), and sample size (n) are included for each group (LA, EE$_{LA}$, EE-only) or lumped group (LA + EE$_{LA}$). Statistical significance of quantitative data was tested using a Wilcox Rank sum test, p-values (p) are included for each group comparison of each question. Statistical significance is marked by an asterisk '*'. Statistical significance is attributed when p-value < 0.05. Likert rating scales from 1 to 5 are included under each question.

			LA	*EE$_{LA}$*	*EE-only*	*LA + EE$_{LA}$*
1	How is this experience meeting your expectations? (Circle one)					
	1 – Far short of my expectations	μ	2.85	2.57	2.8	2.67
	2 – Short of my expectations	σ	0.38	0.76	0.42	0.66
	3 – Equals my expectations	n	7	14	10	21
	4 – Exceeded my expectations	p	LA – EE$_{LA}$ = 0.3404 EE$_{LA}$ – EE-only = 0.3923 LA + EE$_{LA}$ – EE-only = 0.5885			
	5 – Far exceeded my expectations					
2	Working with my group is: (circle one)					
	1 – Extremely difficult	μ	3.14	3.14	3.7	3.14
	2 – Somewhat difficult	σ	1.21	1.10	1.26	1.11
	3 – Neither easy nor difficulty	n	7	14	10	21
	4 – Somewhat easy	p	LA – EE$_{LA}$ = 0.8766 EE$_{LA}$ – EE-only = 0.2503 LA + EE$_{LA}$ – EE-only = 0.2216			
	5 – Extremely easy					
	If there have been difficulties, explain, and describe strategies you've used or could use to address them and improve project outcomes with your team.					
3	How would you rate faculty involvement? (Circle one)					
	1 – Far too little	μ	3.43	2.14	2.3	2.57
	2 – Somewhat too little	σ	0.53	0.66	0.48	0.87
	3 – Just right	n	7	14	10	21
	4 – Somewhat too much	p	LA – EE$_{LA}$ = 0.0013* EE$_{LA}$ – EE-only = 0.6077 LA + EE$_{LA}$ – EE-only = 0.3451			
	5 – Much too much					
4	How would you rate TA involvement? (Circle one)					
	1 – Far too little	μ	3.00	2.79	2.5	2.86
	2 – Somewhat too little	σ	0.00	0.43	0.53	0.36
	3 – Just right	n	7	14	10	21
	4 – Somewhat too much	p	LA – EE$_{LA}$ = 0.3404 EE$_{LA}$ – EE-only = 0.3923 LA + EE$_{LA}$ – EE-only = 0.5885			
	5 – Much too much					

5 What and how have you contributed to the group effort?

6 Do you feel your group equally values the contributions of all its members? If not, please describe

7 How have you split up work between your group members?

8 Please tell us about how your group works together? Describe a typical collaborative work session.

9 Comment on how your initial thoughts about this cross-disciplinary project may or may not be changing as the project has progressed.

Survey 3

Post-collaboration survey given to all students after completion of projects, presentation of designs, and handing in of reports. For quantitative questions, an item analysis including mean (μ), standard deviation (σ), and sample size (n) are included for each group (LA, EE_{LA}, EE-only) or lumped group (LA and EE_{LA}). Statistical significance of quantitative data was tested using a Wilcox Rank sum test, p-values (p) are included for each group comparison of each question. Statistical significance is marked by an asterisk ‘*’. Statistical significance is attributed when p-value < 0.05. Likert rating scales from 1 to 5 are included under each question.

			LA	*EE_{LA}*	*EE-only*	*LA + EE_{LA}*
1	My group communicated well with each other.					
	1 – Strongly disagree	μ	4.00	4.21	4.28	4.14
	2 – Disagree	σ	1.31	1.21	0.89	1.17
	3 – Neutral	n	8	14	18	22
	4 – Agree 5 – Strongly agree	p	LA vs. EE_{LA} = 0.5773 EE_{LA} vs. EE-only = 0.9168 LA and EE_{LA} vs. EE-only = 0.9056			
2	My group communicated well with stakeholders.					
	1 – Strongly disagree	μ	4.63	3.50	3.35	4.13
	2 – Disagree	σ	0.52	1.16	1.22	1.17
	3 – Neutral	n	8	14	17	22
	4 – Agree 5 – Strongly agree	p	LA vs. EE_{LA} = 0.0182* EE_{LA} vs. EE-only = 0.6064 LA and EE_{LA} vs. EE-only = 0.1302			
3	My group worked across disciplines effectively.					
	1 – Strongly disagree	μ	3.88	4.07	4.18	4.00
	2 – Disagree	σ	1.25	0.92	0.98	1.02
	3 – Neutral	n	8	14	11	22
	4 – Agree 5 – Strongly agree	p	LA vs. EE_{LA} = 0.7681 EE_{LA} vs. EE-only = 0.7263 LA and EE_{LA} vs. EE-only = 0.6537			

			LA	*EE_{LA}*	*EE-only*	*LA + EE_{LA}*
4	My opinions were respected at group discussions.					
	1 – Strongly Disagree	μ	4.25	4.57	4.56	4.45
	2 – Disagree	σ	1.39	0.51	0.62	0.91
	3 – Neutral	n	8	14	18	22
	4 – Agree	p	LA vs. EE_{LA} = 1.0000 EE_{LA} vs. EE-only = 0.9471 LA and EE_{LA} vs. EE-only = 0.9245			
	5 – Strongly agree					
5	Other group members had important contributions.					
	1 – Strongly disagree	μ	4.88	4.29	4.56	4.59
	2 – Disagree	σ	0.35	0.51	0.70	0.50
	3 – Neutral	n	8	14	18	22
	4 – Agree	p	LA vs. EE_{LA} = 0.0498* EE_{LA} vs. EE-only = 0.3519 LA and EE_{LA} vs. EE-only = 0.8603			
	5 – Strongly agree					
6	I feel that collaborating with another department enriched my experience in the project. Why or how?					
7	What specific aspects of this collaboration worked well, in your opinion?					
8	What specific aspects of this collaboration would you change?					
9	Please tell us about your experiences in the project this semester (e.g., working with stakeholders, working with another discipline, working on a real world project, etc.).					
10	My group work integrated all the different opinions of group members.					
	1 – Strongly disagree	μ	4.25	4.14	4.33	4.18
	2 – Disagree	σ	0.85	0.66	0.69	0.72
	3 – Neutral	n	8	14	18	22
	4 – Agree	p	LA vs. EE_{LA} = 0.8558 EE_{LA} vs. EE-only = 0.3519 LA and EE_{LA} vs. EE-only = 0.8603			
	5 – Strongly agree					
11	My group always resolved different opinions of members in a constructive manner.					
	1 – Strongly disagree	μ	3.63	4.57	4.33	4.23
	2 – Disagree	σ	1.51	0.51	0.84	1.07
	3 – Neutral	n	8	14	18	22
	4 – Agree	p	LA vs. EE_{LA} = 0.1436 EE_{LA} vs. EE-only = 0.5338 LA and EE_{LA} vs. EE-only = 0.9283			
	5 – Strongly agree					
12	The unique skills and talents of all the members of my group were fully valued and realised.					
	1 – Strongly disagree	μ	3.88	4.57	4.11	4.32
	2 – Disagree	σ	1.46	0.51	0.96	0.99
	3 – Neutral	n	8	14	18	22
	4 – Agree	p	LA vs. EE_{LA} = 0.3421 EE_{LA} vs. EE-only = 0.1847 LA and EE_{LA} vs. EE-only = 0.3816			
	5 – Strongly agree					

			LA	*EE_{LA}*	*EE-only*	*LA + EE_{LA}*
13	Working across disciplinary boundaries (engineering and landscape architecture) enhanced my learning.					
	1 – Strongly disagree	μ	4.63	4.07	3.69	4.27
	2 – Disagree	σ	0.52	0.92	0.95	0.83
	3 – Neutral	n	8	14	13	22
	4 – Agree	p	LA vs. EE_{LA} = 0.1813 EE_{LA} vs. EE-only = 0.3590 LA and EE_{LA} vs. EE-only = 0.0793			
	5 – Strongly agree					
14	Our team was able to integrate concepts from the disciplines of engineering and landscape architecture into the project.					
	1 – Strongly disagree	μ	4.36	4.29	3.08	4.31
	2 – Disagree	σ	0.63	0.73	1.16	0.68
	3 – Neutral	n	7	14	12	21
	4 – Agree	p	LA vs. EE_{LA} = 0.9676 EE_{LA} vs. EE-only = 0.0078* LA and EE_{LA} vs. EE-only = 0.0028*			
	5 – Strongly agree					
15	We used theory and methods from both landscape architecture and engineering in the project.					
	1 – Strongly disagree	μ	4.43	3.92	2.00	4.10
	2 – Disagree	σ	0.53	0.95	1.41	0.85
	3 – Neutral	n	7	13	2	20
	4 – Agree	p	LA vs. EE_{LA} = 0.2679 EE_{LA} vs. EE-only = 0.0780 LA and EE_{LA} vs. EE-only = 0.0401*			
	5 – Strongly agree					
16	Engineers were able to share ideas from their discipline in language that was understood by landscape architect team members.					
	1 – Strongly disagree	μ	4.57	4.21	3.00	4.33
	2 – Disagree	σ	0.53	0.80	1.00	0.73
	3 – Neutral	n	7	14	2	21
	4 – Agree	p	LA vs. EE_{LA} = 0.3693 EE_{LA} vs. EE-only = 0.0733 LA and EE_{LA} vs. EE-only = 0.0354*			
	5 – Strongly agree					
17	Landscape architects were able to share ideas from their discipline in language that was understood by engineering team members.					
	1 – Strongly disagree	μ	4.43	4.36	3.00	4.38
	2 – Disagree	σ	0.53	0.74	0.71	0.67
	3 – Neutral	n	7	14	2	21
	4 – Agree	p	LA vs. EE_{LA} = 1.0000 EE_{LA} vs. EE-only = 0.1709 LA and EE_{LA} vs. EE-only = 0.1206			
	5 – Strongly agree					

			LA	*EE_{LA}*	*EE-only*	*LA + EE_{LA}*
18	Members of my group sometimes disagreed about how to analyse the assigned case.					
	1 – Strongly disagree	μ	3.50	3.21	3.33	3.32
	2 – Disagree	σ	1.19	0.80	0.91	0.95
	3 – Neutral	n	8	14	18	22
	4 – Agree	p	LA vs. EE_{LA} = 0.2735			
	5 – Strongly agree		EE_{LA} vs. EE-only = 0.5999			
			LA and EE_{LA} vs. EE-only = 0.9426			
19	There were conflicting opinions in my group about key issues on the case.					
	1 – Strongly disagree	μ	3.25	2.46	2.56	2.76
	2 – disagree	σ	0.71	0.66	0.92	0.77
	3 – Neutral	n	8	13	18	21
	4 – Agree	p	LA vs. EE_{LA} = 0.0236*			
	5 – Strongly agree		EE_{LA} vs. EE-only = 0.9812			
			LA and EE_{LA} vs. EE-only = 0.2557			
20	The members of my group had disagreements on how to approach the task from time to time.					
	1 – Strongly disagree	μ	3.13	2.79	3.39	2.91
	2 – Disagree	σ	1.46	1.12	0.92	1.23
	3 – Neutral	n	8	14	18	22
	4 – Agree	p	LA vs. EE_{LA} = 0.6233			
	5 – Strongly agree		EE_{LA} vs. EE-only = 0.1364			
			LA and EE_{LA} vs. EE-only = 0.1972			
21	Members of my group felt comfortable to bring up problems and tough issues.					
	1 – Strongly disagree	μ	4.00	4.14	4.00	4.09
	2 – disagree	σ	1.41	0.53	0.84	0.92
	3 – Neutral	n	8	14	18	22
	4 – Agree	p	LA vs. EE_{LA} = 0.6484			
	5 – Strongly agree		EE_{LA} vs. EE-only = 0.7460			
			LA and EE_{LA} vs. EE-only = 0.6113			
22	Members of my group sometimes rejected others for being different.					
	1 – Strongly disagree	μ	2.25	1.71	1.44	1.91
	2 – Disagree	σ	1.39	0.99	0.62	1.15
	3 – Neutral	n	8	14	18	22
	4 – Agree	p	LA vs. EE_{LA} = 0.3573			
	5 – Strongly agree		EE_{LA} vs. EE-only = 0.5880			
			LA and EE_{LA} vs. EE-only = 0.2514			

			LA	*EE_{LA}*	*EE-only*	*$LA + EE_{LA}$*
23	Members of my group had a hard time listening to an opposing point or perspective.					
	1 – Strongly disagree	μ	2.69	2.14	1.53	2.34
	2 – Disagree	σ	1.44	1.23	0.62	1.30
	3 – Neutral	n	8	14	17	22
	4 – Agree	p	LA vs. EE_{LA} = 0.3772 EE_{LA} vs. EE-only = 0.1617 LA and EE_{LA} vs. EE-only = 0.0468*			
	5 – Strongly agree					
24	Members of my team respected each other's opinions.					
	1 – Strongly disagree	μ	3.57	4.43	4.56	4.14
	2 – Disagree	σ	1.59	0.65	0.70	1.10
	3 – Neutral	n	7	14	18	21
	4 – Agree	p	LA vs. EE_{LA} = 0.2301 EE_{LA} vs. EE-only = 0.4721 LA and EE_{LA} vs. EE-only = 0.2145			
	5 – Strongly agree					

Appendix C

Grading rubric for EE final reports

Table 2 Grading rubric for engineering final reports

	Excellent	*Partial credit*	*Needs significant improvement*
Content	5 sound assumptions for all designs and calculations	–1 for each missing assumption –1 for each incorrect assumption	0 missing all assumptions or >5 absences of assumptions
50 pts possible	5 capacity of structures present	–2 for each absence of structure capacity	0 no capacity of structures
	5 return period to fill capacity	–2 for each description of capacity missing	0 missing description of design capacity
	5 overflow structures present	–2 for each missing overflow structure	0 no overflow structures
	5 structures accomplish tasks	2 hard to understand how structure accomplishes task	0 structure does not accomplish intended task
	5 all design parameters included	3 missing design parameters (–1 per design parameter)	0 no design parameters included
	10 correct calculations	5 errors in calculations (–1 for each error)	0 errors in calculations (>5) and assumptions missing
	3 plots have captions	2 figure does not have a description but may have a number	0 no captions
	3 all axes on plots	–1 for each missing axis	
	4 present, caption describing image	2 figures present no captions	0 no figures or captions

Table 2 Grading rubric for engineering final reports (continued)

	Excellent	*Partial credit*	*Needs significant improvement*
Report	2		Title page
50 pts possible	1		Title
	2 author and contact information present	1 missing author or contact info	0 missing both author and contact information
	1 date		0 no date
	2 table of contents	1 missing page number references	0 no page number references
	4 executive summary touches on all important concepts	–1 for each major concept missing	0 no executive summary
	3 intro – holistic, mentions path of the report	2 introduction missing several major points (one-point per point)	0 introduction absent or missing more than three key points
	5 design choices are appropriate to issue and well explained	–1 for each missing design explanation	0 design is hard to follow, missing pieces of explanation
	3 conclusion covers all important points	1 conclusion misses reiterating 2+ important points	0 conclusion is incomplete, does not wrap up report
	4 appendix present, well organised, includes all necessary components	2 appendix is hard to follow, few descriptive phrases, mostly equations	0 appendix is very hard to follow, has mostly excel screenshots as equations
	1 page numbers		0 no page numbers
	1 sections and subsections		0 no sections and subsections
	2 important answers easy to find	1 important answers present but hard to find	0 important calculations/ numbers missing
	1 appropriate usage of images		0 better described with a figure than words
	5 All important information in the report	–2 for each section that should be in the report but missing	0 report is missing more that three key points, or does not discuss implications or reasons behind decisions
	5 all calculations in appendix	–2 for each misplaced set of calculations	0 all calculations in the body of the report
	3 references in text and in own reference section	2 references in text or in own section but not both	0 no references
	3 units	–1 for each missing unit	0 >3 missing units
	2 figures and descriptions not split	–1 for each split figure	0 figures have descriptions split >2 times