The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
Paper ID #42381

Lessons Learned through Multi-Year Team Teaching of an Engineering Course for Pre-College Students

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ABSTRACT

Team teaching or co-teaching has been present in the K-12 systems for decades and has recently become more common in higher education. Team teaching has been proven effective in improving student's knowledge of the subject, increasing student satisfaction due to greater instructor support, and increasing positive perceptions associated with the course [1], [2]. Studies also suggest that team teaching can enhance instructors' professional development by providing a space to support the adoption of evidence-based strategies, transfer of methodologies and tools, critical self-reflection of teaching practices, adoption of improved pedagogy by new instructors, and learning of innovative teaching techniques by more established instructors [3], [4]. Although multi-lecturer courses bring these advantages to students and instructors, they can be difficult to plan, execute, and assess. Some of the challenges reported are consistent messaging, class housekeeping, overlapping roles, the dominance of one discipline, loss of individual autonomy, and poor logistics [2], [5].

This paper discusses a team-taught engineering course for pre-college students. Over the past four years, a team of three to five graduate student instructors has worked to team teach a one-week course. For many instructors, this experience is their first opportunity as a primary instructor. For all of the past instructors, this course was their first experience in team teaching. As such, one of the primary goals of this program is to teach instructors how to develop a unified course and team teach. The instructors meet bi-weekly the semester before the course to facilitate effective team teaching. Over time, many keys to success and additional goals and thoughts for future iterations have been determined. This paper details the instructor recruitment, team building, course development, delivery, and assessment strategies that have worked well for developing team-taught courses. Keys to success include (1) recruiting strategies focused on professional development opportunities for instructors, (2) defined roles and hierarchy, (3) creating a timeline for course development and following the schedule, (4) spending meetings finding common ground on large goals like course outcomes and objectives, (5) developing content separately, but in line with agreed course outcomes and objectives, and (6) developing a relationship characterized by mutual respect among instructors. Other items to be discussed include classroom management, choosing joint instructor versus separate instructor sessions, workload division, and developing a common assessment strategy. Although the instructor group, course deliverables, and students have varied over time, the instructor team has increasingly produced a cohesive course with students expressing interest in pursuing engineering studies.

Tags: pre-college, team teaching, co-teaching, teaching in teams, collaborative teaching, civil engineering

BACKGROUND

Team teaching, a collaborative instructional method traditionally rooted in the K-12 educational system, has recently increased its use in higher education. This pedagogical strategy, which involves multiple instructors jointly conducting a course, has been praised for its effectiveness in improving both student and instructor outcomes. Students report that team teaching has positively impacted their learning and classroom experience [6], and instructors perceive improvement in their leadership skills [7]. These perceptions of team teaching remain across different disciplines and are held by students from diverse backgrounds [8].

The literature unequivocally supports the benefits of team teaching. Recent studies [2], [9] have found that team teaching enhances student knowledge and satisfaction and attributed this success to the diverse instructional perspectives and the heightened level of support. Team teaching is also effective at boosting student self-efficacy and team skills [10]. Furthermore, team teaching facilitates instructors' professional development. Many authors [1], [6], [11] report that instructors who team teach are more likely to adopt evidence-based strategies, critically self-reflect on their courses, and learn innovative teaching techniques. In addition, team teaching is effective at supporting new instructors, particularly in remote teaching, where flexibility and engagement of remote learners are crucial, and a distributed team approach can help in maintaining academic standards [12].

However, the implementation of team teaching also has recognized challenges. Literature [3] highlights issues related to consistent messaging, overlapping roles, and logistical complexities. Consistent messaging and overlapping roles are critical challenges when coordinating class communication, facilitating instructor-team communication, and ensuring all instructors effectively contribute to student learning and engagement [2]. Logistical complexities are also evident in effectively coordinating and collaborating among instructors [13]. These challenges necessitate thoughtful planning, coordinated execution, and frequent assessment of student outcomes to ensure that team teaching remains effective.

In engineering education, team teaching takes on additional layers of complexity. The technical rigor required in engineering courses demands a blend of expert knowledge and pedagogical understanding. However, teaching teams may find it challenging to coordinate professional interaction among skilled instructors and ensure that all perspectives are integrated seamlessly into the course content [14]. In addition, engineering educators may seem reluctant to share a classroom with peers or even uncomfortable at being assessed by students and peers alike [15].

Looking forward, the intersection of team teaching with pre-college engineering education presents a rich avenue for research. There is a need to explore the long-term impacts of such educational strategies on students and novice instructors. Even though the literature provides evidence of increased student participation when team teaching took place [13], little is known about which strategies directly impacted this outcome. In addition, there are limited studies analyzing team teaching in multidisciplinary environments, where the instructors come from different backgrounds to address a common topic, but the existing studies report communication and knowledge gaps among instructors [16].

The following paper explores team-teaching strategy by discussing a team-taught engineering course for pre-college students. This course, led by a diverse team of graduate student instructors, was taught for four years and serves as a benchmark for exploring the multifaceted impacts of team teaching. It also explores the instructors' experiences of teaching and teaching for the first time, presenting an opportunity to learn and grow along with the students. The study discusses strategies the authors found effective to foster a successful team teaching environment, what worked, what was improved, and insights into coordinating a multidisciplinary instructor team.

CLASS LOGISTICS

The study took place in a one-week, one-credit university-level course for pre-college students as an introduction to civil engineering. The course has been taught four times since 2020, starting with online instruction due to the COVID-19 pandemic and going in person during 2021, 2022, and 2023. The curriculum changed every year in response to the arrival of new instructors and has exposed students to several civil engineering sub-disciplines, including structures, transportation, water resources, hydrology, geomatics, architectural engineering, and construction engineering. The course culminated in a team-based final project, aimed at bringing together the topics discussed throughout the week. Daily activities included lab visits, hands-on experiments, active learning sessions, and lectures, conducted in active learning classes as able.

Additionally, the course aimed to enhance graduate students' teaching and course development skills. Doctoral students from various civil engineering fields, selected through a fall semester application process, led the course. They engaged in regular meetings for activity planning and logistical coordination in the months leading up to the summer course. Course preparation involved multiple stages: instructor recruitment and onboarding, syllabus and assessment development, active learning integration, feedback collection, and program effectiveness evaluation. The course's design followed a backward design approach applied by the instructional team from start to finish.

Course logistics have been divided into four activities: (1) recruitment, (2) course development: outcomes and objectives, assessments and activities, (3) delivery, and (4) evaluation. Figure 1 illustrates the course logistics for the course.

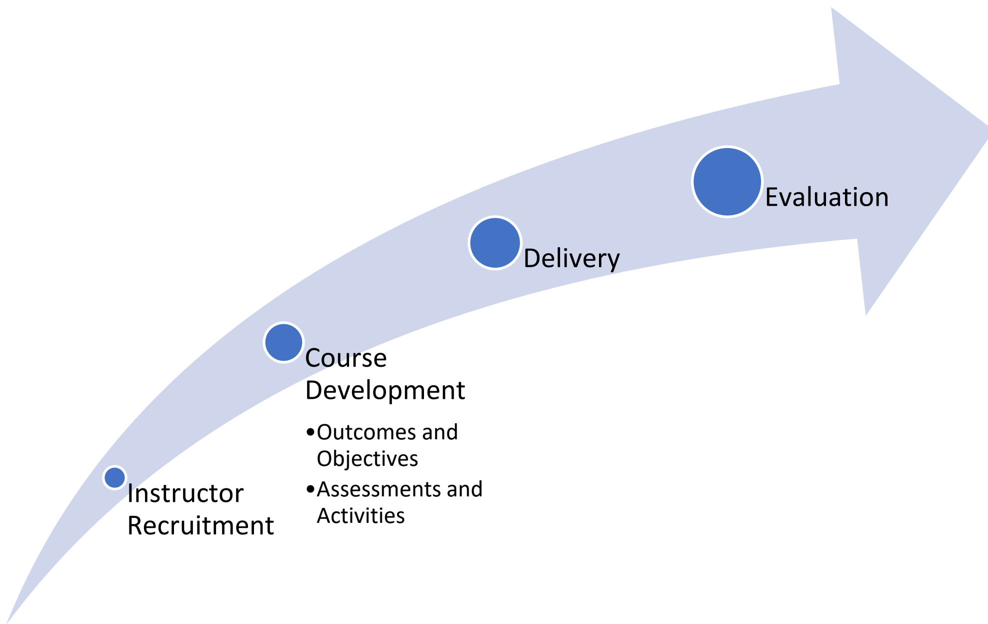

Figure 1. Course logistics for the course

(1) Recruitment

Recruitment happened at two levels: instructor and student. Instructor recruitment occurs during the fall semester, with instructors identified before the spring semester. Recruitment has been refined over time to focus on exposing potential next-year instructors to the course when the previous cohort of pre-college students are on campus and then advertising to prospective instructors at the beginning of the fall semester through email, flyers, graduate student clubs, and word of mouth. Interested students apply by filling out a form where they share their interest in the program, their experience related to the course, how they explain their expertise to a pre-college audience, and the areas of civil engineering they would be primarily teaching. Instructor candidates are then interviewed and selected by mid-October. These instructors then receive course credit and funding as scholarships to support their educational expenses for spring and summer semesters. As the program developed, the program manager introduced the role of a support lead. The support lead was an individual with prior experience as a course instructor whose role was to support course development and provide peer mentoring for new instructors.

Student recruitment occurs throughout the fall semester into the spring semester. Students are generally at least 16 years old and have completed their sophomore year of high school by the time the course begins. Recruitment and admission are the responsibilities of the Purdue University summer program's office in conjunction with the admissions office, with additional advertising from the civil engineering department through social media and department publications. Prospective students are reviewed by the Purdue summer program's office and then recommended for admission. Course personnel have limited input into recruitment but receive relevant info about enrolled students before the course starts. The course enrollment target is 30-40 students.

(2) Course Development

Course development occurs in meetings among instructors as a group and individually outside of meetings. This process includes four steps: development of course outcomes (as a team), development of individual course objectives based on the group outcomes, development of team summative assessments and formative individual assessments, creation of a rubric and feedback mechanisms, and design of course learning activities. Over the years, the team developed definitions for these various aspects based on relevant literature and use cases and have been adapted according to the needs of the course. A copy of these definitions and functional responses to these definitions is included in Table 1.

Table 1. Course definitions for course development

Term	Definition	Function Response
Learning Outcomes (course-level goals)	Upon completion of this course, students will be able to… (do, know, value, etc.)	Write your course-level Learning Outcomes below. Typically, there are 3-5 overall outcomes. Feel free to add rows, as necessary.
Learning Objectives (unit/module/lesson-level goals)	Upon completion of this course, students will be able to… (do, know, value, etc.)	Write your learning objectives in the boxes below, aligned with the larger, course-level learning outcome with which each is associated.
Methods of Assessment	What students will do to demonstrate that they have achieved this learning outcome / objective	Write how you plan to assess each objective / activity in the boxes below (e.g., quiz 1, homework 1 and 2, etc.).
Methods of Grading / Feedback	What students will do to demonstrate that they have achieved this learning outcome / objective & how they will receive feedback	Write how you plan to grade assessments in the boxes below (e.g., rubric, only numerical grading, written feedback).
Learning Activities	What teaching strategies and learning activities will foster this learning outcome	Write activities you want to use in the boxes below (e.g. lecture style, active learning, discussion, debate).

In the first year, the design process involved several iterations with course outcomes and objectives written and then re-written after a better understanding of course factors (including the unexpected impact of COVID-19) and activities that instructors were interested in doing with students. This development process was improved and streamlined in subsequent years to first educate new instructors about backward design and then write course outcomes that are grounded by course factors including one-week course duration and level of education students enrolling in the course typically have.

During this course development process, instructors are challenged to think about how their specific civil engineering area (e.g., structural, water, environmental, construction) connect with other areas to develop course outcomes that encompass the breadth of civil engineering and course learning objectives that compliment instructors in other areas. Based on the discussion of learning outcomes and learning objectives, summative and formative assessments were created. From the initial course offering, the summative assessment of the week is a multi-disciplinary poster project where students work in teams to develop a proposed solution to a provided open-ended problem and then present this project on the final afternoon of the course. Sample problems include solving traffic problems during busy sporting events, designing extraterrestrial habitats, and proposing what the university should do with a parking lot when (in the future) cars drop personnel off and park themselves off-site. These core summative assessments were all guiding assessments that in-class activities and formative assessments were built to support. An example of alignment between course activities in 2022 and 2023 is included in Table 2.

(3) Course Delivery

In conjunction with the course design, a built-out course page in a Learning Management System was developed where students could find relevant course documents, assignment submissions, and timely feedback. This course page released documents as students needed access to them. This element was particularly important in 2020 due to the unexpected virtual delivery of the course and has continued in the subsequent in-person opportunities.

In addition to considering course design topics, course logistics were also a focus of the team. Instructors and students each had to be in various places with various resources at specific times throughout the day. Over the years, the team developed increasingly useful logistics schedules. An example of this schedule is presented in Table 3.

(4) Evaluation

Throughout the course, instructors and students are actively interacting and encouraged to provide feedback via an evaluation survey at the end of the week. The end-of-course survey was administered to the students to gather their perceptions of the course's effectiveness, engagement, and overall learning experience. This survey consisted of a mix of Likert-scale questions and open-ended responses, allowing for quantitative measurement of student satisfaction and qualitative feedback on areas for improvement. Additionally, instructors engaged in a structured debriefing session following the course's conclusion, reviewing student feedback, personal observations, and the course's logistical execution.

The student evaluation survey, in conjunction with instructor exit discussion, was used to evaluate how the course went in that particular year, areas of strength, and opportunities for enhancement. At the conclusion of the course, the survey results were anonymized and aggregated to draw larger trends without singling out individual students. Likert data was processed to yield the mean responses to each question. Common themes from free response questions were identified from the written responses by looking at common words and themes in student responses. Course survey questions and results from the first iteration of the course are included in [17].

Table 2. Example alignment between course activities in 2022 and 2023

Term	Example 1 (2022)	Example 2 (2023)
Learning Outcomes (course-level goals)	Use the design process to create a civil engineering product	Describe the impact of Civil Engineering in improving society
Learning Objectives (unit/module/lesson-level goals)	Categorize possible loads that a civil engineering structure could carry.	Identify at least three different reasons why water is important for humanity
Methods of Assessment	Individual in-class activity provided in handout	Group in-class activity in the whiteboards
Methods of Grading / Feedback	Review of handout responses and feedback provided on Learning Management System	Review and feedback of pictures taken by one person from the group and uploaded to the Learning Management System
Learning Activities	Short recap from previous class (2 min) Think-Pair-Share Activity Think - What loads are structures designed for? (2 min) Pair – What loads is this structure design for, how large are they? (10 min) Share – How do you determine how large the loads are for new structures? (5 min) Introduce ASCE7-16 and AASHTO, discuss different types of loads, and discuss load combinations (15 min) Scavenger hunt through ASCE 7-16 and AASHTO to find specific loads (20 min) Serviceability and other load considerations (10 min) Determine relevant project loads with the team (15 min)	The students are encouraged to form 5 groups of 5 and 3 groups of 6. They will stand up next to movie posters located over the whiteboards. They will write the names of their teammates and choose a captain. The posters are from dystopian sci-fi movies where a water-related problem was the start of the dystopia (5 min) The teams are provided with descriptions of the movies and isolated words. They have to match the words with the description. They also have to identify a fake movie: a movie that does not exist but happened in a real town in the U.S. They have to take a picture and submit it to Brightspace. The first three submissions "win." (10 min) Debrief (5 min)

Table 3. Typical schedule of the course

Time	Event		Who
By 8:00 am	Arrive to Room A		Instructor 1
8:15 am	Start Class, Attendance		Instructor 1
8:15 am	Adaptable Buildings: Designing a Structure for Today and Tomorrow		Instructor 1
9:45 am	Arrive to Room A		Instructor 2
9:50 am	10 min break		Instructor 1, Instructor 2
10:00 am	Costs and benefits of regulating indoor environments		Instructure 2
11:30 am	Break for lunch		
12:45 pm	Arrive to Room B/C		Instructor 3 and 4
1:10 pm	***Group A*** Population growth and roadway capacity (Instructor 3) *Room B*	***Group B*** Construction Equipment For the Future (Instructor 4) *Room C*	Instructor 3 (Room B), Instructor 4 (Room C)
2:20 pm	***Group A*** Team Project Time *Computer Lab (Instructor 2 and 4)* *Room D*	***Group B*** Population growth and roadway capacity (Instructor 3) *Room B*	Instructor 3 (Room D), Instructor 2 and 4 (Room B)
3:30 pm	***Group A*** Construction Equipment for the Future (Instructor 4) *Room C*	***Group B*** Team Project Time *Computer Lab (Instructor 2 and 3)* *Room D*	Instructor 4 (Room C) Instructor 2 and 3 (Room D)
4:45 pm	Students are to be picked up from Building A and taken to dinner.		

Key findings from the student evaluations highlighted the positive impact of the team-teaching approach on their learning experience. Many students noted that the multiple instructors' diversity of perspectives and expertise enhanced their understanding of civil engineering. However, suggestions for improvement included requests for more hands-on activities.

Instructors' reflections revealed the importance of pre-course planning and communication in executing a successful team-taught course. Discussions centered around refining recruitment strategies for both students and instructors, enhancing the clarity and alignment of course objectives with assessments, and improving the logistical coordination of classroom activities and resources. These reflections were instrumental in identifying successful strategies and pinpointing areas requiring adjustment for future course iterations.

LESSONS LEARNED

Through the process of teaching and evaluating the engineering course, several valuable lessons were learned, contributing to the continuous improvement of the program and the scholarship related to team teaching. These lessons include:

1. *The importance of Team Teaching:* Having a different group of instructors team-teach the course allows for the incorporation and collaboration of unique perspectives, including contributions to course content, the inclusion of varied organizational styles, and how instructors show up as leaders and collaborators. The qualities, skills, and knowledge each instructor brings to the course development foster program improvement and efficiency.

2. *Defined Roles and Clear Communication:* Establishing clear roles for each instructor and maintaining open lines of communication, including messaging applications such as WhatsApp or Teams, are crucial for smoothly executing a team-taught course. Instructor writing defined roles and choosing the person in charge of each team-teaching element resulted in positive outcomes since year three. This clarity helps prevent overlapping responsibilities (or responsibilities being missed, like forgetting to bring printed worksheets) and ensures that all instructors are aligned with the course's goals and logistics. Some role examples are meeting leader, final group project coordinator, learning management system coordinator, instructor team content formatter, and group activities coordinator.

3. *Coordination and Logistics*: Bi-weekly in-person team meetings, in addition to the inclusion of a shared communication platform, are impactful in the coordination of multiple instructors. Having a schedule of in-person meetings sets expectations and allows all to devote time to developing the course as a team. In addition, using a collaborative platform that allows for shared file management and shared communication provides a known location where all can access work and correspondence.

4. *Flexibility and Adaptability:* The ability to adapt to unforeseen challenges, such as those presented by the COVID-19 pandemic, is essential. Flexibility in course delivery, whether online or in-person and the ability to adjust teaching strategies to suit the dynamic needs of students are key to maintaining the course's effectiveness. In addition, flexibility to adapt to students' responses to the in-class activities and adapt to shorter or longer times spent on them, particularly when involving active learning. Teams identified key inflexible events, such as when the bus would arrive for a field trip, but allowed other timetables to adjust organically based on student feedback. As this is many instructors' first formal teaching role, there will inevitably be activities that go both shorter and longer than planned.

5. *Student Engagement and Active Learning:* Enhancing student engagement through active learning strategies is vital for fostering a deep understanding of the subject matter, and involving multiple instructors in the learning process helps students see problems from multiple diverse perspectives. This course has benefitted throughout the years from incorporating hands-on activities, group projects, and interactive discussions to engage

students actively in their learning process, but also to allow instructor collaboration and peer support. Particularly for hands-on activities, students have benefited from having multiple instructors available to ask questions, reducing the student-to-instructor ratio and decreasing the amount of knowledge one instructor needs to be an in-class expert.

6. *Feedback Mechanisms:* Implementing robust feedback mechanisms for both students and instructors plays a significant role in the course's continuous improvement. Student evaluations offer valuable insights into their learning experience, while instructor debriefings provide a platform for reflection and collaborative planning for future courses. Based on this feedback, the course topic was shifted from resiliency and sustainability to a more general introduction to civil engineering. Additionally, optional instructor in-class evaluations and changes to the interview process were implemented.

7. *Professional Development for Instructors:* The team teaching model offers a unique professional development opportunity for instructors, particularly those new to teaching. Future courses will continue to emphasize recruiting diverse instructional teams and support their development through pre-course onboarding and ongoing mentorship.

8. *Assessment and Grading Strategies:* Developing a common assessment strategy that aligns with the course's learning objectives is crucial for accurately measuring student learning outcomes. In initial iterations of the course, some students mentioned differing grading and assessment difficulty as a barrier and frustration in the course. Over time, a more consistent assessment strategy has emerged where the final group project is increasingly fair, transparent, and conducive to learning. Moreover, individual feedback to formative assessments is more direct, personalized, and guiding to achieve the course's learning outcomes.

The multi-year experience of team teaching the engineering course has yielded significant insights into the benefits and challenges of this instructional approach. The lessons learned through evaluation and reflection have laid a strong foundation for future enhancements, with a continued focus on improving student learning outcomes, instructor development, and course logistics. These insights will guide the refinement of team teaching strategies for this course and as a model for similar educational initiatives in engineering and beyond.

CONCLUSIONS

This paper has explored the intricacies and outcomes of implementing a team teaching strategy in a pre-college engineering course, created by a group of graduate student instructors over multiple years and facilitated by the department’s program creator and manager. The initiative aimed to enhance the pre-college students' educational experience while providing a professional development platform for novice instructors. Through the lens of this multi-year endeavor, we have obtained valuable insights into the efficacy of team teaching in an engineering educational context, highlighted the challenges encountered, and outlined the strategies that contributed to the program's success.

The conclusions drawn from this exploration showcase the multifaceted benefits of team teaching, both for students and instructors. The diversity of instructional perspectives and expertise enhanced students' learning experience, broadening their understanding of civil engineering and its societal impacts. The collaborative nature of the course design and delivery fostered an engaging learning environment, encouraging active participation and critical thinking among students. The feedback gathered through end-of-course evaluations pointed to high levels of student satisfaction and interest in pursuing engineering studies, validating the effectiveness of the team teaching approach in stimulating student engagement and interest in the field.

For instructors, the team teaching model served as a significant professional development opportunity, particularly beneficial for those in the early stages of their teaching careers. The collaborative planning and execution of the course enabled instructors to learn from one another, adopt evidence-based teaching strategies, and reflect critically on their teaching practices. This experience enhanced their pedagogical skills and fostered a sense of community and mutual support among the instructor team. The challenges encountered, such as the need for clear communication and role definition, provided essential learning opportunities, leading to the refinement of strategies for successful team teaching.

The study also highlighted the importance of adaptability and resilience in facing unforeseen challenges, such as those posed by the COVID-19 pandemic. The ability to pivot to online instruction and subsequently reintegrate in-person elements denoted the necessity of flexible course design and delivery strategies. This adaptability ensured the continuity and effectiveness of the educational experience, despite external disruptions.

Reflecting on the lessons learned through this team teaching initiative, it is evident that the benefits extend beyond the immediate educational outcomes. The collaborative model contributes to developing a supportive instructional community, promotes the exchange of diverse pedagogical perspectives, and encourages innovative approaches to engineering education. The insights gained from this experience have broader implications for implementing team teaching strategies in higher education, particularly in disciplines that benefit from multidisciplinary approaches.

As the instructors prepare for future courses, the continued exploration and refinement of team teaching methodologies will be crucial in addressing the evolving needs of students and instructors alike. The framework and set of processes presented in this work were developed through multiple years to create a unified and collaborative course. Although this allows for large amounts of coordination between instructors, it has been noticed that additional effort toward collaboration, especially between lesson plans, could elevate the course. Future versions of the course will intentionally guide individual instructors to compare and contrast their lesson plans with their fellow instructors' plans to highlight potential areas of collaboration while ensuring that the content is unified between each class session.

The lessons learned from this work provide a valuable framework for enhancing team teaching practices, potentially significantly impacting the quality and inclusivity of engineering education. The success of the team-taught engineering design course for pre-college students serves as a testament to the power of collaborative teaching and the transformative potential it holds for both student learning and instructor development.

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