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The Implementation and Assessment of the Effectiveness of Peer-Teaching Instructional Technique in Lecture and Laboratory Courses

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Introduction

Peer teaching is based on Bandura's social learning theory, Piaget's cognitive development, and Vygotsky's social constructivist learning theory [1-2], in which knowledge is socially constructed by consensus among peers. The basic principle of peer teaching is that teaching something to others is an effective way to learn it [2-3]. Peer teaching involves students acting as both teachers and learners, assisting each other in gaining knowledge and understanding through interdependence [4]. By teaching others, students deepen their understanding and conduct more research to help peers comprehend the material. Peer teaching promotes active engagement with course material, deepening students' understanding [2].

The term "peer teaching" is used within papers associated with peer mentoring [5], peer review of work [6], peer collaboration, peer cooperation, peer discussion on assignments both in-class and out-of-class [7-11], peer assessment/evaluation/feedback of work [6], peer tutoring [12-13], and peer teaching with senior or graduate students teaching freshmen concepts [14-16]. Much of the available research is focused on collaboration either in-class or out-of-class through informal or formal learning communities [7-10, 17]. A few papers present pairing of experienced and inexperienced students to significantly improve learning for both; the experienced students learn more by explaining the material to the inexperienced students [18-19]. Others present the creation of "student learning teams" to enhance learning through a team concept [20]. The few papers that focus on students learning a concept that they teach to their peers, highlight the increased learning for the student teaching the concept, and a somewhat increased learning by the other students (if only at the surface level) because the lesson being taught from a different viewpoint because it is taught by their peers [21-30]. The authors of the cited literature highlight the benefits of peer teaching, such as improved understanding of concepts, development of communication and leadership skills, and increased engagement in the learning process. Additionally, they discuss the importance of faculty being a part of the student's preparation to improve self-efficacy and quality of the content.

From 2020 to 2022, a faculty who specializes in Geotechnical Engineering at The Citadel, a teaching-focused institution in the Southeast United States, utilized four peer teaching techniques in Introduction to Geotechnical Engineering, Geotechnical Engineering laboratory, and Mechanics of Materials (Table 1).

Table 1. Peer teaching methods used in this study.

Peer Teaching Method	Course
Reciprocal Teaching	Introduction to Geotechnical Engineering
Proctor Model	Geotechnical Engineering Lab
Jigsaw Method	Mechanics of Materials
Collaborative In-Class Assignment	Mechanics of Materials

The goals of this study are to (1) discuss the institutional context and peer teaching techniques used in lecture and lab courses, and (2) evaluate whether different peer teaching methods are as effective as instructor-led instruction in enhancing student learning.

Course Format

At The Citadel, Civil Engineering (CE) majors must take the Introduction to Geotechnical Engineering course in their senior year. The course covers engineering uses of soils; laboratory and field determination of soil properties; determination of phase relationships; engineering soil classification; soil-water interaction; stress effects of loading on soils at depth; and consolidation, compaction, shear strength, bearing capacity theory, and several special geotechnical topics. It is offered in the fall semester, with day classes meeting three times a week (50 minutes each) and evening classes meeting twice a week (75 minutes each). Day classes are populated by students of traditional age and evening classes are populated with students who live in the local community, many of whom work full- or part-time and are predominately non-traditional students. This course was taught in-person in 2021 and 2022.

CE majors must take the one-credit Geotechnical Engineering lab during their senior year, which meets for 110 minutes once a week. Experimental topics include particle size distribution; clay soil consistency; engineering classification; permeability; compaction; consolidation; and shear strength parameter determination. It is available in both day and evening programs in the spring semester and was offered in-person in spring 2021.

CE majors take Mechanics of Materials in their first semester of junior year, while Mechanical Engineering (ME) majors take it in their second semester of sophomore year. The course is available in fall, spring, and summer, consisting of 2.5 hours of lecture per week. It is a three-credit course required for Introduction to Geotechnical Engineering with a minimum grade of C. Topics include elastic properties of structural materials; internal stresses and strains; principal stresses and strains including Mohr's Circle; axial; torsion; flexure; shear; bolted joints; combined stresses; shear and moment diagrams; and beam deflections. Mechanics of Materials was offered virtually in summer 2020 and in-person in summer 2021.

Pedagogies Used in Instructor-led Courses

The instructor used various active learning techniques in Geotechnical and Mechanics of Materials courses, including web-based pre-class responses, physical models, open-ended homework, case studies, formative assessments, and others. The lab course employed an open-ended discovery approach and real-world application assignments, requiring student-client communication. All courses and sections were taught by one individual instructor.

Peer Teaching Techniques Used in Peer-led Courses

In fall 2021, Reciprocal Teaching [31] was implemented in the Introduction to Geotechnical Engineering course. This approach involved students taking turns teaching topics such as geosynthetics, soil liquefaction, soil stabilization, geotextile applications, and slope stability analysis. The reciprocal peer teaching method enabled students to learn from one another through structured activities. Students prepared interactive 15-20-minute lessons for their peers, ensuring these sessions were not one-sided presentations. Each student led a lesson with learning objectives, hands-on activities, peer questioning, predictions, summaries, and clarifications. Some students used learning games like Kahoot and Jeopardy for the questioning. Peer questioning and prediction tasks ensured peers met student-defined objectives. The instructor collaborated closely with peer teachers, discussing content, and providing insights and clarifications. This approach enabled students to deepen their understanding of geotechnical topics, develop leadership skills, and overcome challenges in mastering and explaining concepts to struggling peers [32]. In our institution, developing leadership skills is an essential competency, and students are taught leadership content to achieve this.

In spring 2021, the Proctor Model [33] was implemented in one section of the Geotechnical Engineering lab. With the Proctor model, a more experienced student teaches less experienced peers [33]. Two students enrolled in the course, who were familiar with various geotechnical testing methods, were recruited and took the role of peer teachers for lab experiments. Peer teachers met with the instructor before each experiment to discuss background theory and receive guidance. Following each meeting with the instructor, peer teachers recorded geotechnical testing videos, prepared in-class presentations, and posted pre-lab questions on the course website. During each lab, peer teachers presented to peers and mentored student groups working on the experiment. The peer teachers facilitated the lab experiments, including sieve analysis, hydrometer analysis, Atterberg limits testing, compaction testing, hydraulic conductivity testing, direct shear testing, and 1-D consolidation testing.

In summer 2021, the Mechanics of Materials course utilized Collaborative In-class Assignment and Jigsaw methodologies to promote a deep understanding of the material and engage students directly. Collaborative in-class assignments involved student teams discussing course concepts and solving problems together. Teams of three, with members grouped by Grade Point Average (GPA), remained consistent throughout the semester. Each team included a member with a GPA over 3.5, a member with a GPA between 3.0 and 3.5, and a member with a GPA under 3.0. In-class team problem solving reinforced key concepts and promoted peer teaching. Each team was assigned a distinct problem to solve and then explained their solution to the class. Team roles included a recorder, responsible for documenting solutions, a coordinator, facilitating discussion, and a reviewer, monitoring time and guiding the team. Reviewers and recorders collaborated to ensure accuracy, and all team members provided feedback. Member positions were shuffled during the semester.

The Jigsaw methodology was implemented to ensure each student developed expertise in a specific subcategory and contributed to the group's learning. Students were divided into "expert groups," with each student researching a subcategory of the lesson [34]. Expert groups then met to discuss and enhance their understanding before returning to their home group to teach their subcategory [34]. This approach promoted collaboration, deep understanding, and comprehensive learning across all subcategories.

In the Mechanics of Materials course, the Jigsaw methodology was used in a "combined loading Jigsaw activity" involving axial stress, bending stress, transverse shear stress, and constructing a stress element at a point on a T-shaped flexural member. Students began in home groups, each focusing on one topic, collaborating to answer questions. They then joined groups with one student from each expert group to teach their topic to others. Finally, home groups created posters presenting their solutions to the entire class.

Study Methods

The study aims to determine the effectiveness of various peer teaching methodologies, such as Reciprocal Teaching, Proctor Model, Collaborative In-class Assignment, and Jigsaw, compared to instructor-led instruction in enhancing student learning. Student proficiency in course learning outcomes was measured using final exam questions, and students in the peer-led sections also completed a self-perception survey on the benefits of peer teaching. Figure 1 summarizes participant characteristics. Of the total, 86% were CE majors, 14% were ME majors, and 97% were first-time course takers. Class standing was 75% seniors, 11% juniors, and 14% sophomores. The peer-led sections had 72 students, while the instructor-led sections had 83.

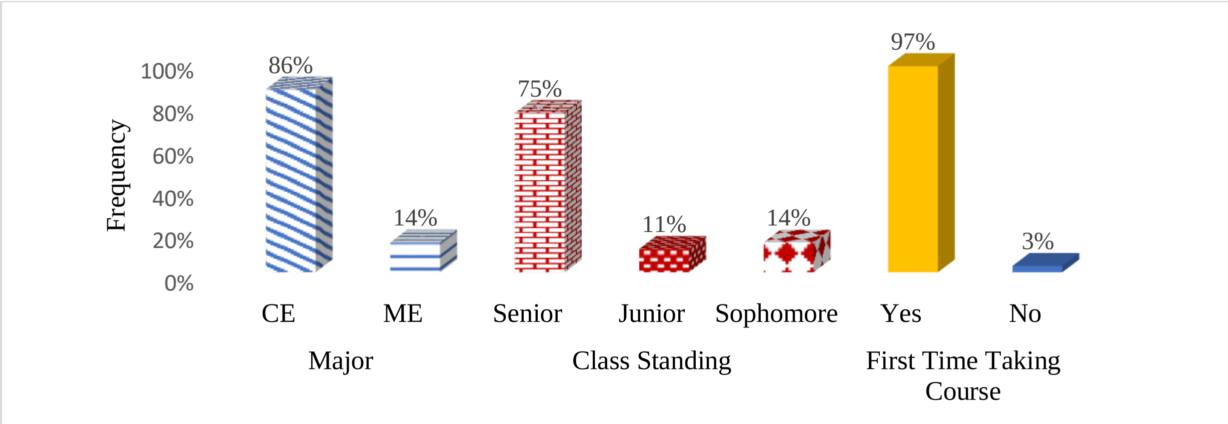

Figure 1. A summary of the participants' characteristics.

Direct assessment data for the Introduction to Geotechnical Engineering course included student performance on soil liquefaction, soil stabilization, and geotextile applications questions on the final exam. The exams were identical for both peer-led and instructor-led sections, graded by the same instructor using a standard solution and rubric. Figure 2 shows the means and the standard errors of the scores on the final exam for peer-led and instructor-led sections. The peer-led sections (Mean = 82.3) outperformed the instructor-led sections (Mean = 80.9) by approximately 1.5%. Statistical analysis using a t-test with a significance level of 0.05 showed no significant difference between the peer-led and instructor-led section scores (p-value = 0.09).

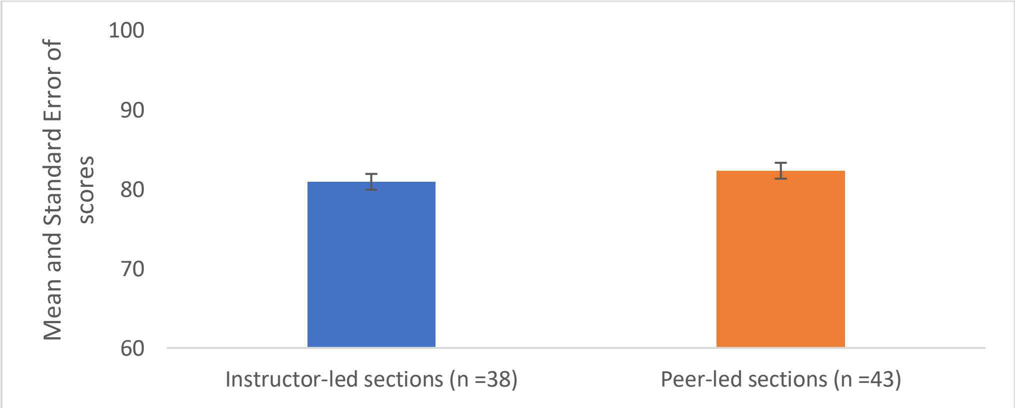

Figure 2. Comparison of final exam results for the instructor-led and peer-led sections in Introduction to Geotechnical Engineering.

Direct assessment for the Geotechnical Engineering lab sections included student performance on the final exam in spring 2021. The exams were identical for both peer-led and instructor-led sections, graded by the same instructor using established solutions and a grading rubric. Figure 3 illustrates the means and the standard errors of the scores on the final exam for both peer-led and instructor- led sections. The mean scores on the final exam were 86.9 for peer-led section and 82.7 for instructor-led sections, showing a 4.2% increase in student performance for the peer-led lab section. A two-sample t-test showed a statistically significant difference (p-value < 0.05) between the mean scores of the peer-led and instructor-led sections.

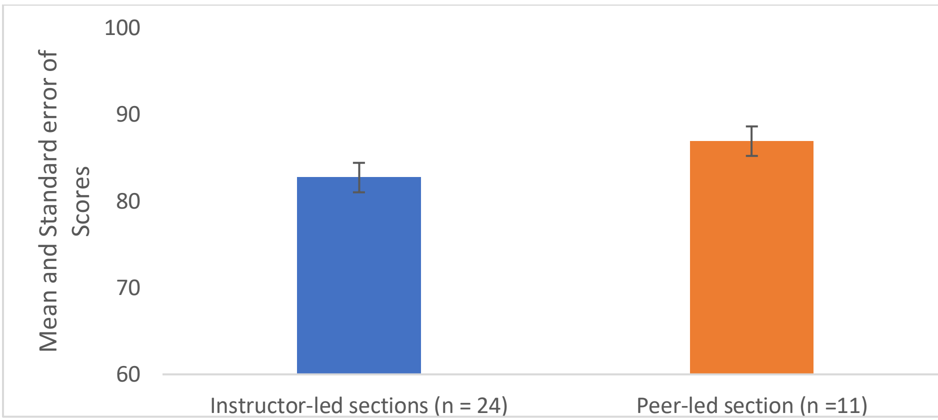

Figure 3. Comparison of final exam results for the instructor-led and peer-led sections in Geotechnical Engineering lab.

Direct assessment for the Mechanics of Materials course included student performance on the final exam, which was identical for both peer-led and instructor-led sections. The exams were graded by the same instructor using an established solution and grading rubric. Figure 4 shows the means and standard errors of the scores on the final exams for both the peer-led and instructor-led sections. The peer-led section (Mean = 83.7) slightly outperformed the instructor-led section (Mean = 82.5). A two-sample t-test showed no significant difference (p-value = 0.10) between the mean scores of the peer-led and instructor-led sections.

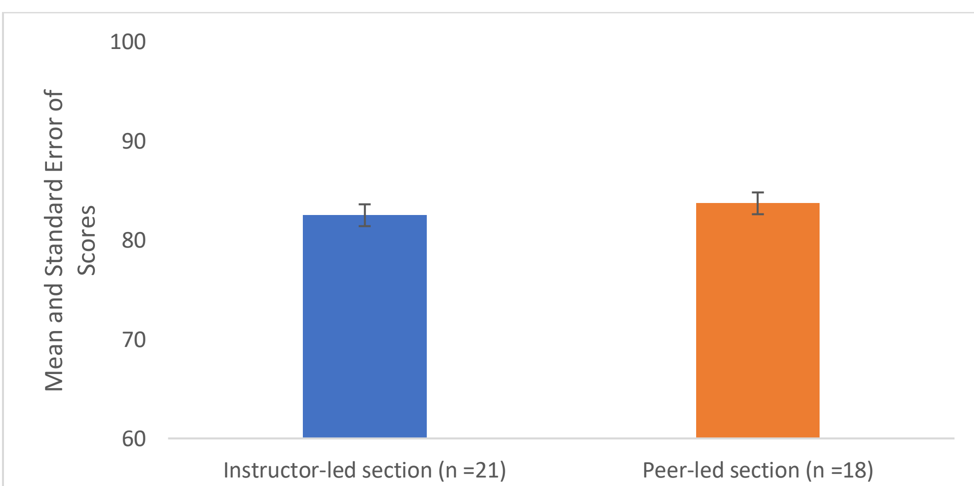

Figure 4. Comparison of final exam results for the instructor-led and peer-led sections in Mechanics of Materials.

Survey of Student Perception of Benefits of Peer Teaching

From 2020 to 2022, indirect assessment data were collected through a self-perception survey on peer teaching in Introduction to Geotechnical Engineering, Geotechnical Engineering lab and Mechanics of Materials. The survey used a 10-question pre- and post-survey on a 5-point Likert scale to gauge students' perceptions (Table 2). Cronbach's alpha was used to test the reliability of the survey ($\alpha = 0.72$), indicating sufficient consistency among items. Factor analysis confirmed construct validity across all items by examining the underlying structure of the survey instrument and ensuring the items are indeed measuring the intended constructs and no other unrelated factors. The analysis revealed that all items were correlated to each other and the mean inter-item correlations for all questions ranged from 0.42 to 0.67.

Pre-surveys were administered at the beginning of the semester, and the same survey was conducted at the end to assess peer teaching effectiveness. The response rates for Introduction to Geotechnical Engineering (Fall 2021), Geotechnical Engineering lab (Spring 2021), and Mechanics of Materials (Summer 2021) were 35%, 91%, and 67%, respectively, with a total of 37 out of 72 students (51%) completing both the pre- and post-survey at the peer-led sections.

Table 2. Student perception of peer teaching survey.

	Strongly Disagree	Disagree	Neural	Agree	Strongly Agree
Q1. Peer teaching increases the amount of interaction with other students.	1	2	3	4	5
Q2. Peer teaching enhances the effectiveness of learning outcomes.	1	2	3	4	5
Q3. I can develop new skills and knowledge from peers.	1	2	3	4	5
Q4. Peer teaching helps me to share my knowledge and experiences with peers.	1	2	3	4	5
Q5. Incorporating peer teaching into a course can enhance my learning experience.	1	2	3	4	5
Q6. Direct interaction between students promotes active learning.	1	2	3	4	5
Q7. Peer teachers and students share a similar dialogue, allowing for greater understanding.	1	2	3	4	5
Q8. Peer teaching helps me feel connected to other students.	1	2	3	4	5
Q9. Peer teachers reinforce their own learning by teaching others.	1	2	3	4	5
Q10. Students feel more comfortable when interacting with a peer.	1	2	3	4	5

Mean and standard error were calculated for each question of the pre- and post-survey, with results shown in Figure 5. Mean perception scores varied from 2.9 to 4 and 4.2 to 4.7 on the pre- and post-surveys, respectively. The post-survey indicated the effectiveness of peer teaching, with significant changes in responses. For example, the percentage of students agreeing that peer teaching enhances their learning experience increased from 10% to 90%. Overall, at least 85% of students agreed or strongly agreed with all 10 statements in the post-survey, indicating a positive attitude toward peer teaching.

A statistical analysis was conducted on the pre- and post-survey data to detect changes in students' perception of peer teaching over the semester. The two-sample t-test of unequal variances at a five percent significance level was used to compare the pre- and post-survey scores. All post-survey responses were significantly different from the pre-survey responses, indicating that students generally agreed or strongly agreed with all statements after experiencing peer teaching.

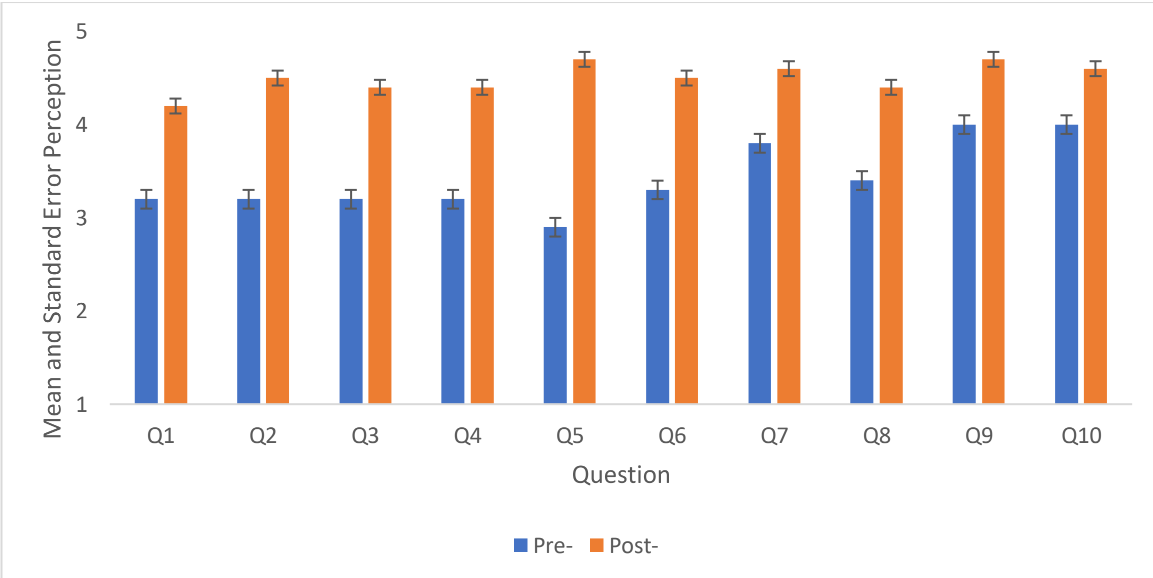

Figure 5. Mean and standard error of pre- and post- survey of students' perception of peer teaching.

Figure 6 illustrates the mean and standard error of students' perceptions for the post-survey across the three courses. For the Geotechnical Engineering lab, the mean perception response ranged from 4.4 to 4.9. For the Introduction to Geotechnical Engineering, the mean perception varied from 4 to 4.6. The mean perception response for Mechanics of Materials ranged from 4.2 to 4.7. In all three groups, the statement "Incorporating peer teaching into a course can enhance my learning experience" (Q5) resulted in the highest mean. Figure 6 shows that the peer-led students in all three courses agreed that peer teaching promotes active learning, enhances learning outcomes and the learning experience, reinforces their own learning, and helps develop new skills and knowledge.

One-way analysis of variance (ANOVA) was performed to determine if the perception of students regarding peer teaching at the end of the semester differed across the three subjects. The results showed that the difference between the mean perceptions among the three subjects was not statistically significant at a 5% level.

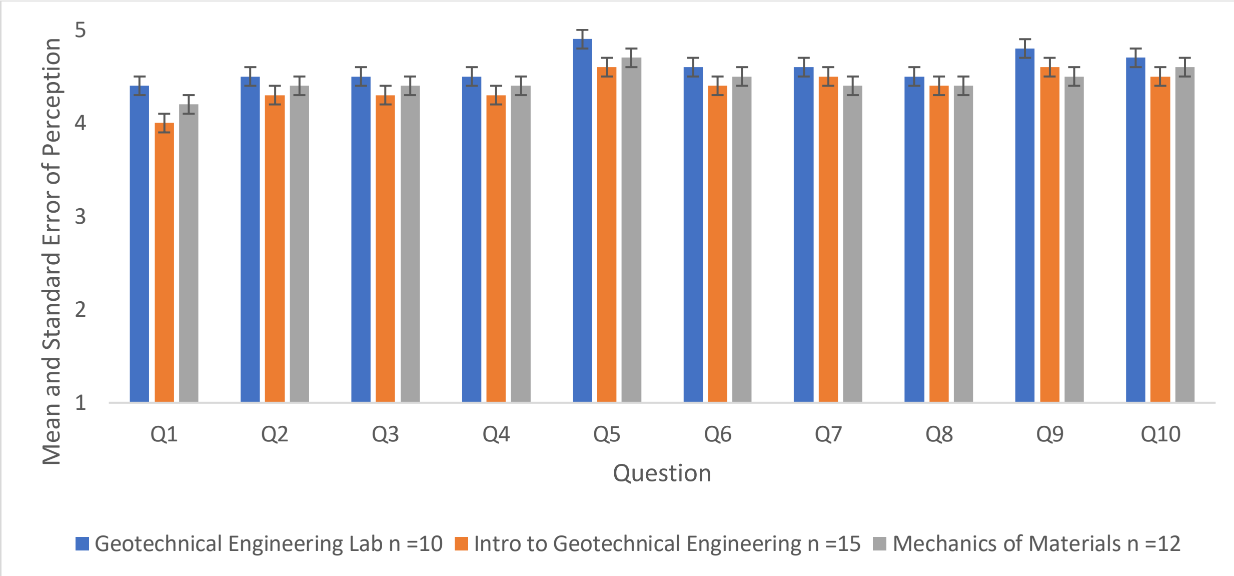

Figure 6. Mean and standard error of students' perception of peer teaching for the post-survey across three courses.

Conclusions

From 2020 to 2022, Geotechnical Engineering faculty at The Citadel utilized peer teaching techniques in both lecture and lab courses. The effectiveness of these techniques was evaluated by comparing the summative assessment results of peer-led and instructor-led sections and by surveying students' perceptions. While the differences between peer-led and instructor-led sections were not statistically significant in lecture courses, they were significant in the lab course. Students' perceptions of peer teaching were consistently positive, as indicated by post-survey responses. In this study, peer-led students across all courses and sections perceived that peer teaching promotes active learning, enhances learning outcomes and the learning experience, reinforces their own learning, and develops new skills and knowledge. Engineering faculty can create a more engaging and effective learning environment in their courses by incorporating some of the strategies used in this study.

Due to the small sample size, it is challenging to make conclusive recommendations based on the observations. The results of this study, limited to the data from 2020-2022, should not be generalized to broader conclusions. Further data collection and analysis over several more course offerings are necessary to draw informative conclusions. Future studies should encompass different courses with larger sample sizes.

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