A Multi-Institutional Study of Pre- and Post-Course Knowledge Surveys in Undergraduate Geotechnical Engineering Courses

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Introduction

Geotechnical engineering is not a list of procedures, but a list of challenges[1]. Geotechnical engineering projects are designed and analyzed based on data available at a particular site, which in turn are subject to quality and budget considerations. Two project sites are highly unlikely to share the same subsurface conditions[1,2,3]. Thus, solving a geotechnical engineering problem heavily relies on a strong understanding of the basic principles of soil mechanics and a significant amount of judgment. In most introductory geotechnical engineering courses, there is often too much emphasis on methods and not enough on concepts and principles[3]. In addition, most junior and senior Civil Engineering majors enter an introductory geotechnical engineering course with almost no prior knowledge in geotechnical engineering or geology.

The objectives of this multi-institutional study were to (1) assess the amount of exposure students have to geotechnical engineering prior to the introductory course, and (2) to assess student learning as a result of various pedagogical techniques used. The study was carried out at four institutions with Civil Engineering programs, three of which are predominantly undergraduate (with an emphasis on teaching) and one of which is a large research institution. Two of these universities are private, and two are public:

- The Citadel: small public university in the Southern U.S.
- Merrimack College: small private university in the Northeast U.S.
- University of Evansville: small private university in the Central U.S.
- Virginia Tech University: large public research university in the Eastern U.S.

A background knowledge probe (pre-test) and course knowledge survey (post-test) were developed based on key concepts in geotechnical engineering to assess students' prior exposure and knowledge gained in an introductory course. The pre-tests were administered to measure students' prior geotechnical knowledge and to identify student misconceptions at the beginning of each semester. The same short-answer test (post-test) was administered on the last day of the semester to assess knowledge gained as a result of the course experience. Data were collected over the span of two years at The Citadel and Merrimack College, and over one year at University of Evansville and Virginia Tech University. This paper discusses the institutional context, instructional techniques used at each institution, the analyses of pre- and post-test results, and suggestions for future research.

Institutional context and course format

The Citadel enrolls approximately 2,300 in its undergraduate Corps of Cadets (mostly students of traditional age) and approximately 1,000 undergraduate civilian students (mostly students of nontraditional age); and small percentages of female and minorities. As a requirement for graduation, Civil Engineering majors must take two geotechnical engineering courses in their senior year. The first course focuses on basic principles of soil mechanics (i.e., 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, and bearing capacity theory) and the second course focuses on the analysis and design of foundations. The first geotechnical engineering course is offered in the fall semester in both the day and evening programs. The laboratory portion of the first geotechnical engineering course is offered as co-requisite to the second geotechnical course in both day and evening programs in the spring semester. Day classes are taken primarily by members of the Corps of Cadets (Citadel-Day), meeting three times week (50 minutes each). A relatively small percentage of the classes are occupied by active duty or veteran students, who take day classes with the Corps of Cadets. Evening classes meet twice a week (75 minutes each) and are populated with students who live in the community (Citadel-Eve), many of whom work full or part-time. Veterans that have been approved for day status may also attend evening classes in the fall and spring.

Merrimack College is an independent college in the Catholic tradition with undergraduate and master's programs in liberal arts, business, engineering, science, and education. This institution has a total enrollment of 3,300 (2,900 undergraduate and 400 graduate); in Civil Engineering, there are approximately 100 undergraduate and 25 graduate students. All undergraduate Civil Engineering majors are required to complete two courses in geotechnical engineering: (1) an introductory course in geotechnical engineering (Geotechnical Engineering, typically completed during the fall semester of their junior year), and (2) a design elective in geotechnical engineering during their senior year (either Foundation Engineering or Earth Slopes and Retaining Structures). The first course in geotechnical engineering, which emphasizes soil mechanics, is a four-credit course that meets for 2.5 hours of lecture (twice a week for 75 minutes each) and 2.5 hours of laboratory per week. Lecture and laboratory topics include soil composition and classification, compaction, groundwater, stress, settlement, shear strength, and an introduction to foundations and earth-retaining structures. For their second course in geotechnical engineering, students must select one or two geotechnical design electives, which are four-credit courses that meet twice a week for 1.75 hours each. Most undergraduate students complete Foundation Engineering during the fall semester of their senior year; this course, as its name suggests, focuses on the analysis and design of shallow and deep foundations. Students particularly interested in geotechnical engineering will also complete Earth Slopes and Retaining Structures during the spring semester of their junior or senior year; this course covers slope stability and lateral earth pressure theories related to excavations and retaining structures, as well as the analysis and design of retaining walls, sheet-pile walls, and braced and unbraced excavations. Both geotechnical design electives are also available to master's students, although graduate students usually comprise less than 10% of the course enrollment.

The total enrollment at University of Evansville is approximately 2,500 (including full and part-time, undergraduate, adult, graduate and the students in its study abroad campus). As a requirement for graduation, Civil Engineering majors must take two geotechnical engineering courses, one during their junior year (Soil Mechanics and Soil Behavior) and another course during their senior year (Geotechnical Engineering). The first course is offered in the spring semester of junior year (3 credit hours) and it primarily focuses on the index and engineering properties of soils. The topics covered include laboratory and field tests on soils, weight volume relationships, soil classification, principles of effective stress, stress distribution, in-situ stresses in soil, permeability, seepage, laboratory and field compaction, theory of consolidation, elastic and consolidation settlement, time rate of settlement, and shear strength of cohesive and cohesion-less soil. The second course focuses on the analysis and design of foundations. The class meets three times a week for 50 minutes each. The students also take a one-credit-hour soil mechanics laboratory. The students take the three-credit-hour second course (Geotechnical Engineering) during fall semester of the senior year. This course deals with the application of soil mechanics to the design of building foundations (both shallow and deep foundation systems), stability analysis of earth slopes, lateral earth pressure analysis and design of retaining walls. Subsoil exploration and seismic site characterization are also covered in this course. This course typically meets for two 75 minute lectures per week. More than 90% of the students who take these two courses are traditional undergraduate Civil Engineering majors.

The total undergraduate enrollment at Virginia Tech University is approximately 30,000 (on- and off-campus). Out of these, 10,000 belong to the College of Engineering and within that, 550 are Civil and Environmental Engineering majors. As a requirement for graduation, Civil Engineering majors have to take seven out of eight Fundamental courses, one of which is Introduction to Geotechnical Engineering. Almost 100% of the Civil Engineering majors take this course, yielding a total of 100 students per semester, split in two or three sections, depending on the number of available instructors. Furthermore, they need to complete four advanced classes within three specialty areas (seven in total). Other advanced undergraduate geotechnical courses offered are: Methods in Geotechnical Engineering, Earth Pressures and Foundation Structures, Design of Earth Structures, Natural Disaster Mitigation and Introduction to Marine and Coastal Geotechnics. These classes typically attract approximately 20 students with a fluctuation through the years. The Introduction to Geotechnical Engineering course, a three-credit course offered every semester and during the summer has a lecture and a laboratory component. Topics covered include: engineering properties of soils (soil formation and deposition, soil mineralogy and structure, engineering description of soil), mechanics in soils (flow of water, stresses, consolidation, strength of soil) and slightly applications of principles (bearing capacity and foundation design). The laboratory component overlaps, but not entirely, with the lecture topics focusing on: index properties and soil classification, visual soil classification, subsurface characterization, Proctor compaction, mechanically stabilized earth systems, consolidation and time rate of consolidation, shear strength and applications. For the laboratory sections, students are broken into groups of 10 and meet bi-weekly, while the lectures, (based on which this survey was conducted) met twice per week for 75 minutes each time.

Pedagogical Techniques used at The Citadel

Various active learning techniques were employed at The Citadel to improve the student learning of key geotechnical concepts. These included: pre-class reading responses on the course website; analyzing geotechnical failures; using physical models; employing "real world" homework assignments; games; minute papers; and a number of other pedagogical techniques.

Web-based pre-class reading responses[4] were used to motivate students to prepare for class regularly. Students were required to respond to one or two open-ended questions on the course website prior to each lesson. Before each lesson, student responses were examined, and the in-class activities were tailored to meet their actual needs[4]. Physical models were developed and used to demonstrate the key geotechnical concepts. Frequently, clickers were employed to assess the understanding of geotechnical concepts, create an environment to engage students, and provide immediate feedback to both students and instructor[5]. At the end of each lesson, the One-Minute paper[6] was used to monitor student learning and address students' misconceptions and preconceptions. Students were typically asked to write a concise summary of the presented topic, write an exam question for the topic, or answer a big-picture question from the material that was presented in the current or previous lesson in 60 seconds.

The real world open-ended homework assignments directly linked to the course learning objectives[7] were devised to scaffold student understanding of the key geotechnical concepts. The assigned homework not only stimulated creativity and deep thinking about the material, but also required them to use their engineering judgment. To further deepen the understanding of the geotechnical concepts, students were asked to select a geotechnical failure and conduct an in-depth study of why the failure occurred through the exploration of journal articles, websites, and textbooks. Students were also required to explain the mechanism(s) of failure using the concepts learned in the course and compose a technical report documenting the findings of the analysis.

The use of games in the classroom can also be an effective tool to address the diverse learning styles[8]. Literature also states that games can add flexibility to the classroom and allow students to adjust to the way in which they learn best[9]. Another positive outcome of using games in the classroom is that participation in them makes learning a matter of direct experience[10]. To review for the midterm exams, Jeopardy-style questions were used, which required students to display mastery of key geotechnical concepts that goes beyond simple memorization. Category topics for the Jeopardy game included: geology, clay mineralogy, phase diagrams, Atterberg limits, soil classifications, and compaction (see Appendix A, Figure A1). Students were also asked to create geotechnical engineering crossword puzzles in their collaborative groups (see Appendix A, Figure A2). Once constructed, the puzzles had to be solved by other groups in the class. The use of the games in an introductory geotechnical engineering course truly encouraged students to take a greater degree of responsibility for their learning [8-10]. In addition, it allowed them to become more active participants of the learning process and made them feel more in control of their own learning and thinking[8-10].

Pedagogical Techniques used at Merrimack College

A number of pedagogical techniques were employed at Merrimack College to enhance students' learning of geotechnical engineering concepts, similar to the other institutions in this study. The instructor is a recent graduate of the American Society of Civil Engineers (ASCE) Excellence in Civil Engineering Education (ExCEEd) workshop, and has worked to incorporate numerous aspects of the ExCEEd Teaching Model[11] in the course. The course instructor places a large emphasis on structured organization, engaging presentation, enthusiasm, positive rapport with students, and frequent assessment of student learning. The primary mode of instruction is the chalkboard, with daily outlines and handouts to supplement the board notes. In addition, physical demonstrations and slideshows of geotechnical engineering phenomena supplement the chalkboard instruction. The instructor frequently applies active learning techniques (e.g., questioning, group exercises) to enhance students' interaction in the classroom. Throughout the semester, a large number of historical and current events are used to illustrate geotechnical engineering concepts. Most predominantly, the levee failures during Hurricane Katrina are used as a curricular arc throughout the semester[12]. During the first week, a detailed lesson on the

Hurricane Katrina levee failures is presented, and then students are engaged throughout the semester in discussions about the linkages between various curricular topics and Hurricane Katrina (e.g., soil classification, compaction, groundwater, consolidation, shear strength). Nearly all geotechnical engineering concepts can be exemplified in one way or another by the levee failures during Hurricane Katrina. The instructor also organized some field trips to construction projects throughout the term, to aid students in understanding the course material in a broader context.

Pedagogical Techniques used at University of Evansville

At University of Evansville, a variety of interactive teaching methods were used to effectively introduce the soil mechanics concepts to students. Some successful methods used in the class were assigning open-ended critical thinking problems, in-class group problem work sessions, quizzes, use of short videos, and use of instant poll and assigning projects. Along with homework problems from the textbook, many critical thinking open-ended problems were also assigned after each chapter. To explain and reinforce conceptual ideas, many practical problems were solved in the class. Solving problems as a group in the classroom was highly encouraged and teams of three to four worked together to solve some challenging practical problems. Students were quizzed at the end of each chapter from the assigned reading materials. A few simple class demonstrations were performed to reinforce the concepts they learned in class. The course was taught in a way that the students learned the soil testing related concepts in the classroom and performed the same labs that week as a part their laboratory course. An instant polling system using their phones was introduced to gauge the student understanding of soil mechanics and soil behavior. Students liked seeing their response immediately on screen, which helped them to receive immediate feedback. Many students tend to retain things that they see visually. To assist them, many short videos (approximately 3-5 minutes) were shown to explain some concepts and case studies. Project-based learning also played an important role in the two courses taught.

Pedagogical Techniques used at Virginia Tech University

At Virginia Tech University, the instructor employed a large variety of activities and teaching styles targeting various learning processes of the students. This becomes particularly important in large and long classes where students tend to lose their focus. Several aspects from the ExCEEd model[16] were employed as well, mainly targeting building rapport with the students and asking questions throughout the lectures. Typically, the lecture started with an overview of previous and upcoming topics in an effort to create a consistent thread. Each lecture was accompanied with partially-completed handouts paired up with a digital or blackboard presentation. In doing so, students knew at all times where to focus since the handouts already included the necessary illustrations. This method assisted the students with focusing on the essential concepts rather than having to draw an example problem. Some variability was introduced by including demonstrations (when applicable) or short videos that would stimulate some introductory discussions on each day's topic. For example, for the topic of quicksand and upward flow, a short video clip of people sinking in quicksand was shown. In the remainder of the lecture, the applicable principles and equations were derived towards assessing whether it would be actually possible for a human being to sink in sand. This example has been employed by international Geotechnical Engineering professors as well with significant positive effects on student's learning. Interactions with students were encouraged by asking default type questions or calling them to the board in return for some small reward (typically candy). The instructor always placed a great emphasis on the "big-picture" perspective and the importance of each topic within the broader applications of geotechnical engineering.

Study Methods

The broad dataset of student results on the pre- and post-test instruments, coupled with institutional variations in curriculum and pedagogical techniques, allow for an opportunity to assess student's prior knowledge and learning gains at these four institutions. The following describe the guiding research questions for this study:

1. To what degree do junior or senior Civil Engineering majors at various (i.e., public, private, research or teaching focused) institutions have exposure to geotechnical engineering prior to the introductory geotechnical engineering course? What misconceptions do the students have at the beginning of the course, and how could these be improved?

2. What do the students gain in conceptual understanding about geotechnical engineering from the beginning of the course to the end at various institutions?

Assessment Measure

A ten-question background knowledge probe (pre-test) and course knowledge survey (post-test) were developed based upon the key concepts in an introductory geotechnical engineering course and the material from prerequisite courses (see Table 1). The pre-tests were administered to measure students' prior geotechnical knowledge and to identify student misconceptions at the beginning of each semester. The same short-answer test was administered on the last day of the semester to assess knowledge gained as a result of the course experience. It is important to note that neither the pre-test nor post-test counted toward the course grade. In this study, the term 'learning' refers to actual improvement in measureable knowledge regarding geotechnical concepts.

Participants

A total of 197 students completed both the pre-test and post-test at the four institutions. A summary of the students' characteristics in this study is shown in Figure 1. Figure 1 illustrates that 93% of the students in this study did not have any prior experience in geotechnical engineering and 71% of the students were taking an introductory geotechnical engineering course in their senior year.

Table 1. The short-answer questions on the pre- and post-test

No.	Question	Geotechnical concepts assessed
Q1	What are some of engineering characteristics of fine-grained soils?	Engineering characteristics of fine-grained soils
Q2	What does high relative density and low void ratio indicate?	Interpretation of index properties of soils
Q3	Why do we need to assess the shear strength of soil?	Significance of assessing shear strength
Q4	What is the difference between compaction and consolidation?	Compaction vs. consolidation
Q5	Why do we compact soils in earthwork?	Significance of compaction
Q6	Why is determination of water content of soil important?	Significance of water content
Q7	What causes settlement in soils (i.e., sources of settlement in soils)?	Sources of settlement in soils
Q8	What is the difference between normally consolidated and over-consolidated clay?	Prediction of consolidation settlement
Q9	What is difference between the drained condition and undrained condition?	Determination of shear strength / water flow through soils
Q10	The major and minor principal stresses at a certain point in the ground are 450 and 200 kPa, respectively. Determine the maximum shear stress at this point.	Interpretation of Mohr circle of stresses

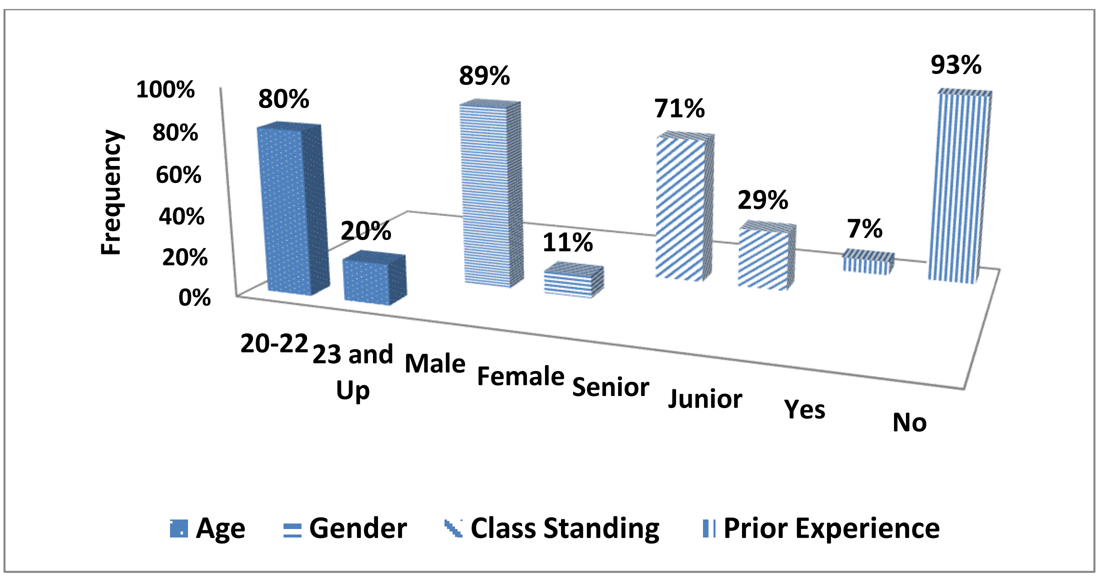


Figure 1. A summary of participants' characteristics (n = 197)

Results and Discussion

The results of the multi-institutional study of the introductory geotechnical engineering course are organized according to each research question.

Research Question 1: To what degree do junior or senior Civil Engineering majors at various institutions have exposure to geotechnical engineering prior to the introductory geotechnical engineering course?

Figure 2 shows the distribution of the pre-test scores for all students in this study (n =197). The pre-test scores ranged from zero to seven out of 10 possible points. Fifty-nine percent of day students and 38% of evening students from The Citadel and 42% of students from Evansville University scored zero or one on the pre-test. Fifty-one percent and 41 percent of students from Merrimack College and Virginia Tech University scored between 4 and 6 on the pre-test, respectively. Figures 3 and 4 illustrate comparisons of students' prior knowledge (i.e., pre-test scores) for public vs. private and teaching-focused vs. research-focused institutions in this study, respectively. Figure 3 depicts that students at the two private institutions in this study performed slightly better on the pre-test than students at the two public institutions, and Figure 4 illustrates that students at the research institution performed better on the pre-test than students at the three teaching-oriented institutions.

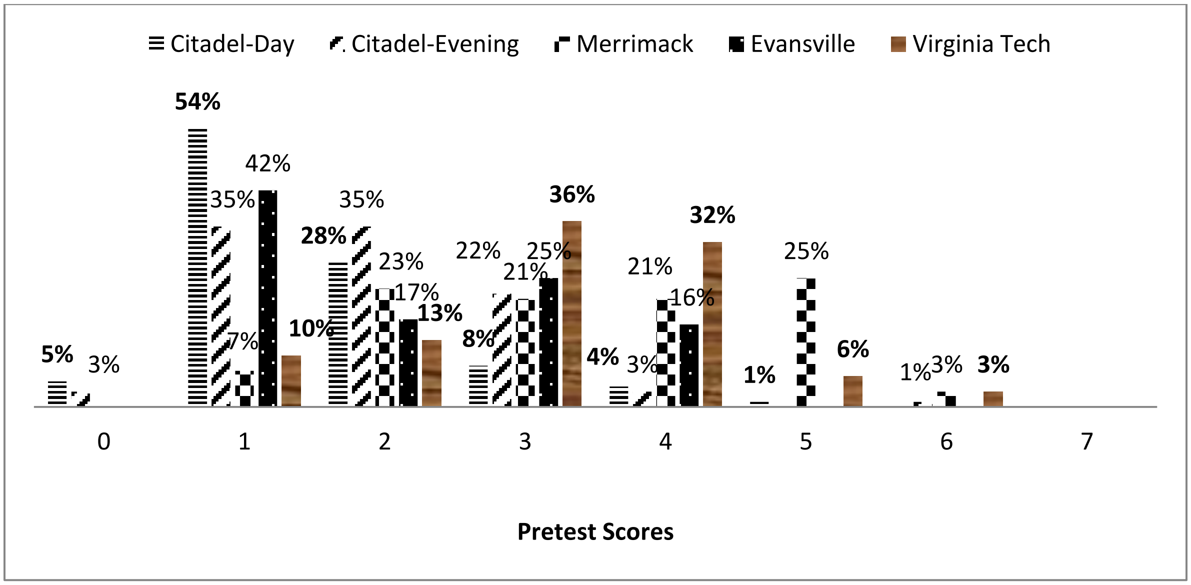


Figure 2. Distribution of scores on the pre-test

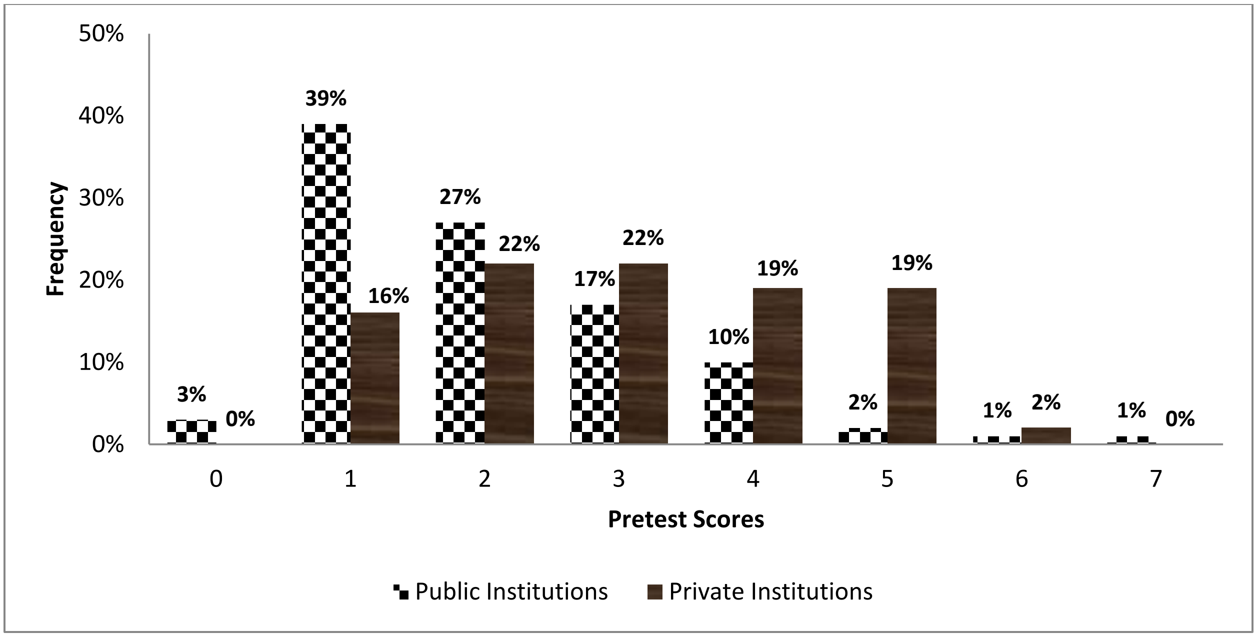


Figure 3. Comparison of pre-test results at public vs. private institutions in this study

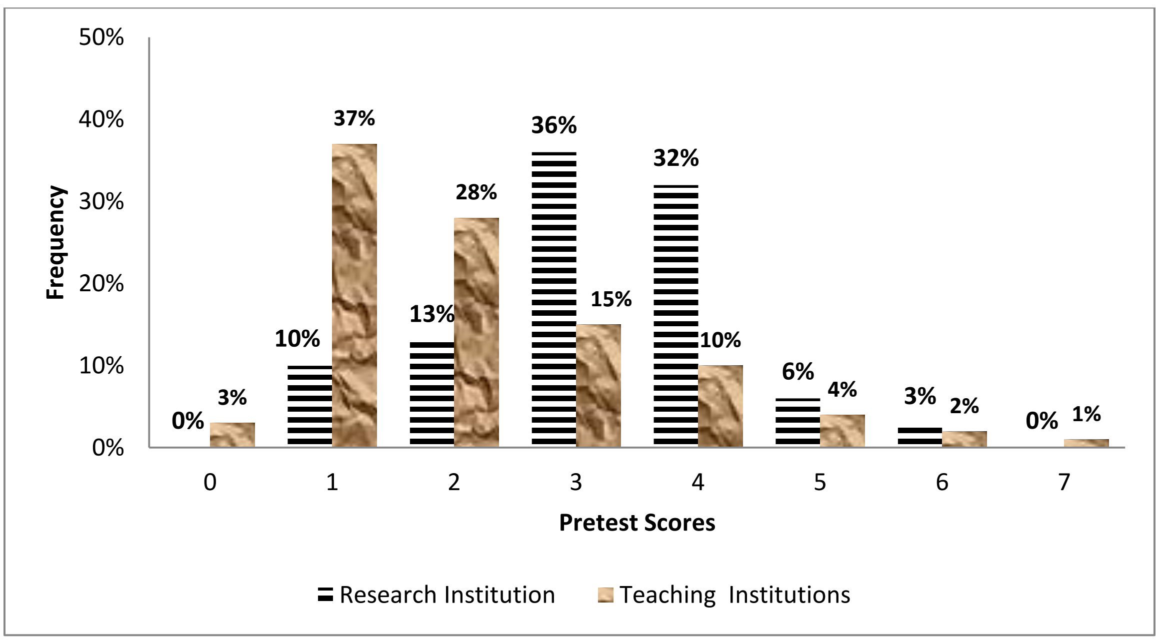


Figure 4. Comparison of pre-test results at research vs. teaching institutions in this study

Figure 5 illustrates the students' performance on each question on the pre-test across institutions in this study. The percentage of students that correctly responded to Questions 1, 2, 4, 7, 8, 9, and 10 ranged from three to thirty, nineteen to forty-seven, zero to thirty-two, zero to five, zero to thirty-seven, and zero to eight, respectively. The percentage of students that correctly answered Questions 3, 5, and 6 ranged from thirty-three to eighty-three, thirty-eight to ninetyseven, and three to seventy-six, respectively. Student's high pre-test performance on certain questions suggests that they are sufficiently able to apply their prior knowledge to certain aspects of geotechnical engineering. The question with the highest pre-test score (Question 5) concerns the significance of compaction. A number of students have had prior experience in construction, landscaping, or other outdoor activities, and are aware of the importance of compaction. Two other questions with high performance are Question 2 (index properties of soils) and Question 3 (significance of assessing shear strength). Although students are not likely to be aware of the geotechnical definition of relative density or void ratio prior to taking a course in soil mechanics, they can correctly assume that high relative density (or low void ratio) suggests a strong soil. Similarly, they are able to correctly apply their knowledge of mechanics of materials (stress, strength, and failure) in Question 3, recognizing the significance of assessing the shear strength of soils.

Students' lowest performances on the pre-test are on Question 4 (compaction vs. consolidation), Question 8 (normally consolidated vs. over-consolidated clays), and Question 10 (Mohr Circle). The low performance on Questions 4 and 8 is not surprising, as students are not expected to have wide exposure to these concepts prior to completing a course in soil mechanics. However, students' pre-test scores on Question 10 (a classic Mohr Circle question) were lower than expected, despite the fact that a course in mechanics of materials is a prerequisite for geotechnical engineering courses at all the institutions in this study. These low scores suggest that students do not adequately retain Mohr circle concepts between their initial exposure in Mechanics of Materials and the start of their introductory geotechnical engineering course. Furthermore, the Mohr Circle is usually taught differently in Mechanics of Materials compared to Geotechnical Engineering; example presentations of Mohr Circle concepts in these two courses are presented in Appendix B. Although the underlying concepts are essentially the same, there are differences in notation, sign convention, and analysis method (analytical vs. graphical). These differences perhaps make it difficult for the students to transfer their prior knowledge to geotechnical engineering course.

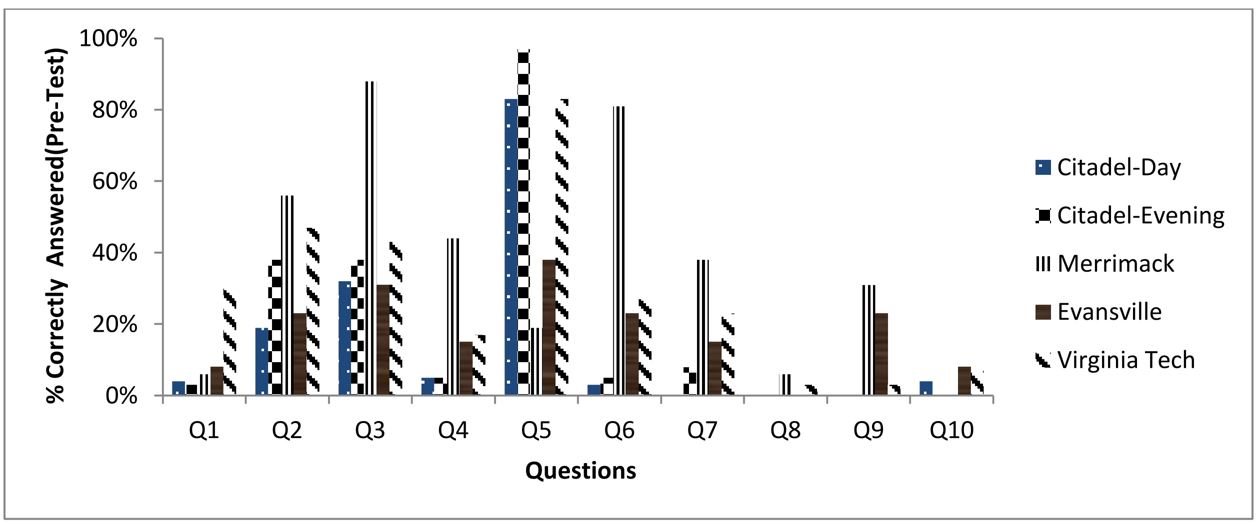


Figure 5. Comparison of results for the 10 pre-test questions across institutions

Figure 6 and 7 provide a global overview of students' prior understanding of geotechnical concepts in an introductory geotechnical engineering course at various institutions in this study. Figure 6 depicts that there were some significant differences between students' pre-test scores for public and private institutions in this study (most notably on Questions 3, 5, 6, and 9), although the performance on other questions was similar. The differences in Figure 7 are not as predominant as those in Figure 6, suggesting that the distinction between research vs. teaching institutions is smaller than public vs. private institutions with regards to students' prior understanding of geotechnical engineering concepts. One question with a notable difference in Figure 7 is Question 1, in which students at the research institution displayed a stronger understanding of the engineering characteristics of fine-grained soils than students at the teaching institutions. Further research can elucidate why the differences are accentuated when comparing public versus private but not when comparing teaching versus research institutions.

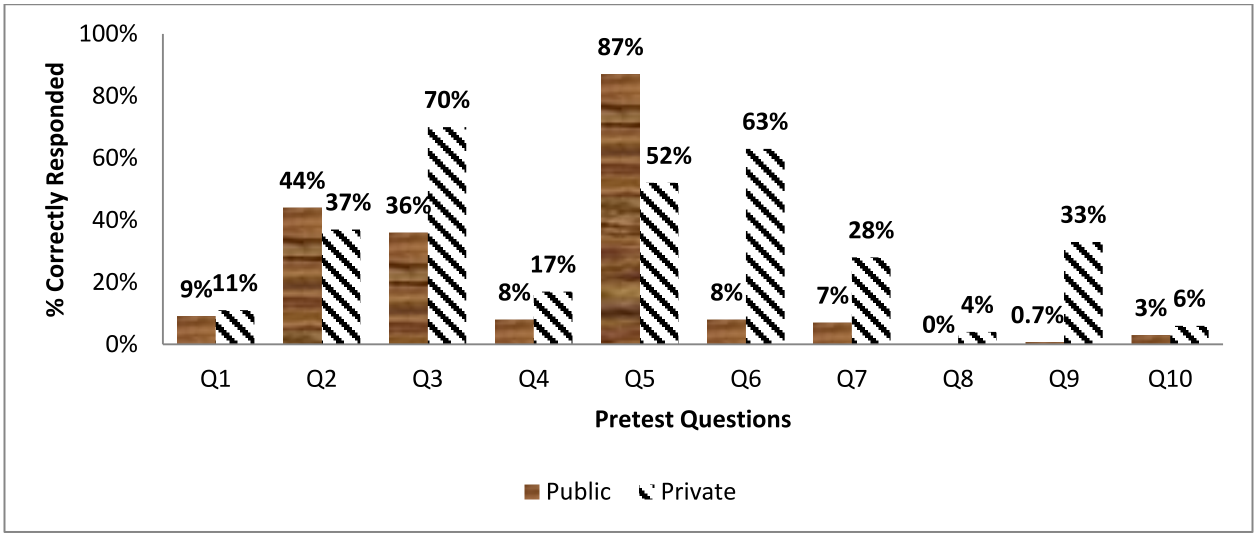


Figure 6. Comparison of results for 10 pre-test questions at public vs. private institutions in this study

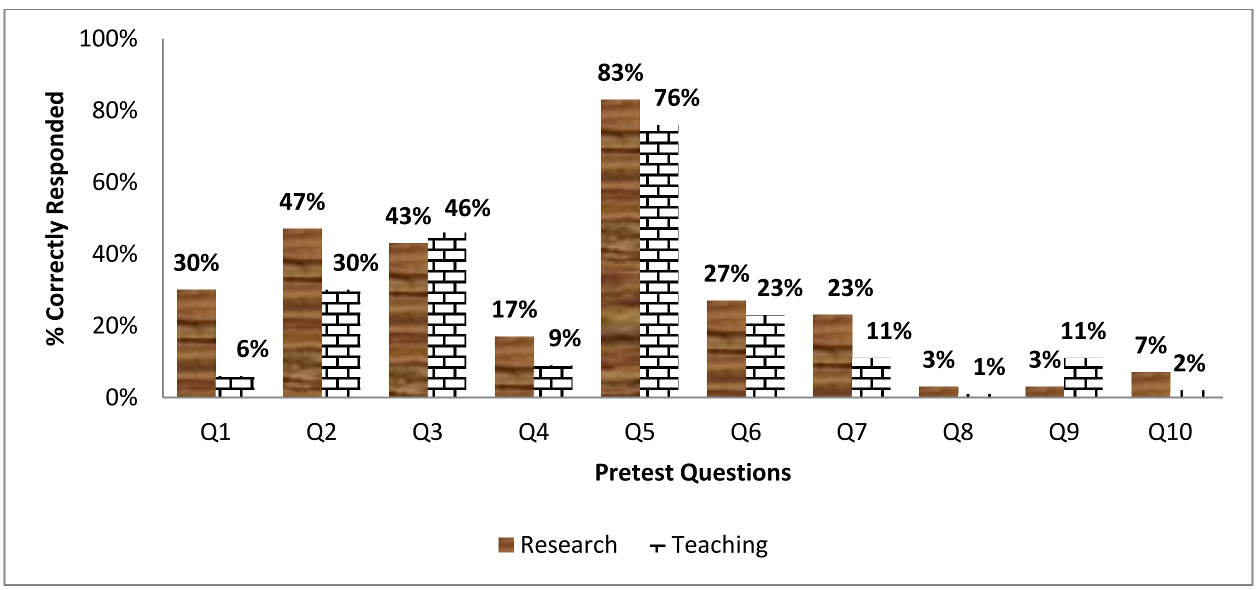


Figure 7. Comparison of results for 10 pre-test questions at research vs. teaching institutions in this study

Research Question 2: What do the students gain in conceptual understanding about geotechnical engineering from the beginning of the course to the end at various institutions?

The same short-answer test in Table 1 was administered on the last day of semester to assess knowledge gained as a result of the course experience. Figure 8 illustrates the mean and standard deviation of overall scores on the pre and post-test across the institutions in this study. The pretest mean and standard deviation range from 19% to 28% and 20% to 27%, respectively. The post-test mean and standard deviation range from 69% to 80% and 12% to 15%, respectively. When analyzing the results of the pre-tests and post-tests as a whole, there are relatively small differences between public vs. private and research vs. teaching institutions. The relative difference between pre- and post-test means stay constant regardless of the comparison and standard deviation drops significantly, indicating less scatter in the-admittedly-improved post-test results.

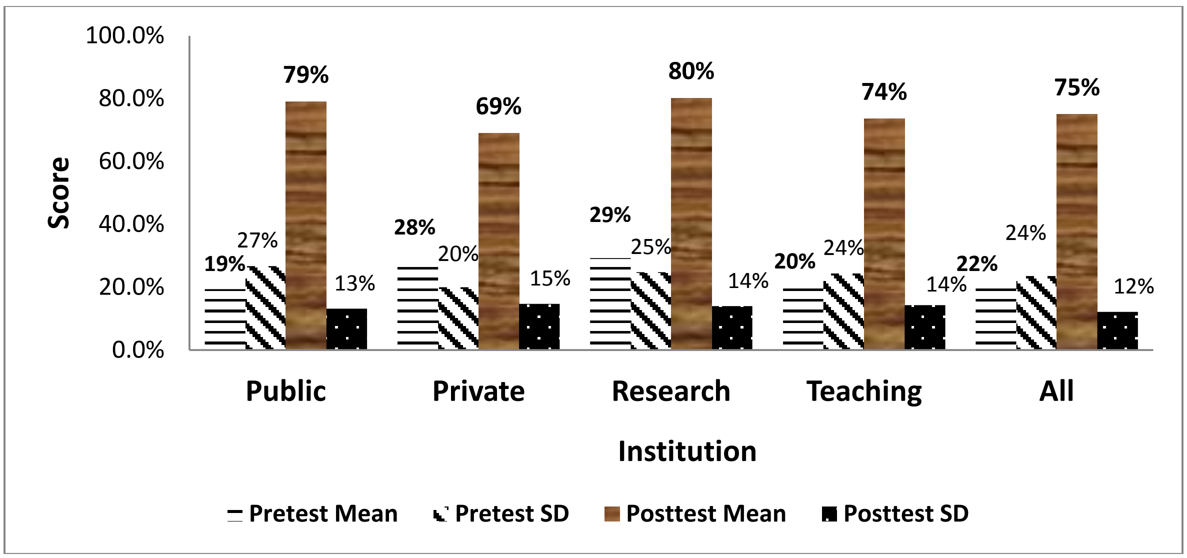


Figure 8. Pre-test and post-test mean and standard deviation for all, public, private, teaching and research institutions in this study

Figure 9 further analyzes students' performance on each question on the pre-test and post-test. Student performance at below 10% level on Questions 1, 4, 8, 9, and 10 of the pre-test is an extremely poor performance, indicating little to no prior experience with these concepts.

Students performed poorly on both the pre-test and post-test on Questions 1 and 10 (over 70% of the student population missed these on both pre-test and post-test). This suggests that students have a poor understanding of engineering characteristics of fine-grained soils and Mohr Circle of stresses. Ninety-one percent on the pre-test and thirty-two percent on the post-test revealed the misconception about the characteristics of fine grained soils (Question 1). Question 10 deals with the interpretation of the Mohr Circle, a topic normally covered in the prerequisite courses. The mean pre-test score for all participants was 5% and the mean post-test for all participants was 58% (as shown in Figure 10). Ninety-five percent on the pre-test and 42% on the post-test exhibited their misconception about Mohr Circle. The majority of students in this study entered and exited the course with a poor understanding of interpretation of the Mohr Circle of stresses. In addition, this may suggest that the current approaches to instruction are not adequate enough to produce conceptual change.

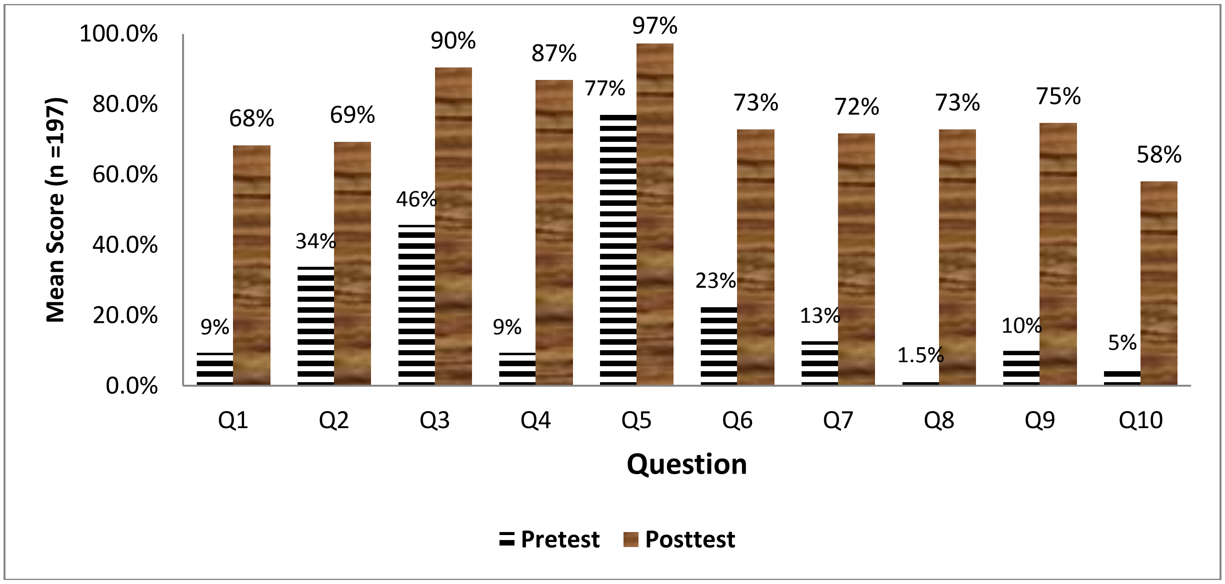


Figure 9. Mean score for each question on the pre- and post-test

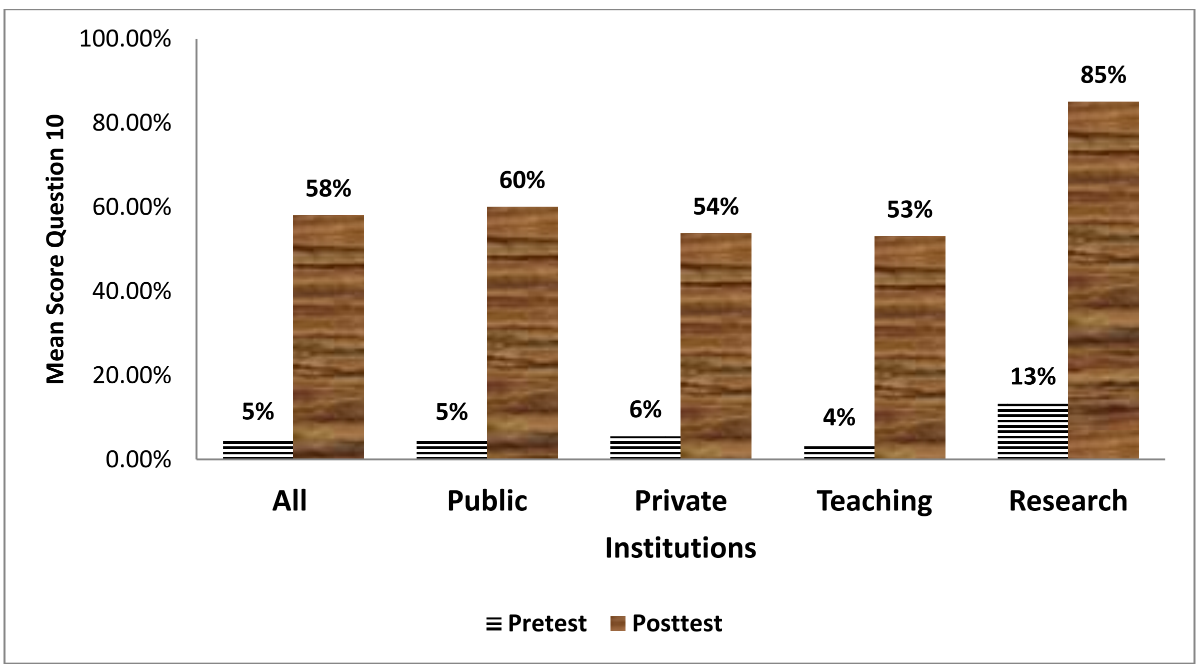


Figure 10. Results of pre-test and post-test for Question 10 (interpretation of Mohr Circle)

Students at the teaching-focused institutions showed significant growth from pre-test to post-test in total score and Questions 1, 3, 5, 6, 7, 8, 9, and 10. However, students in a research-focused institution did not show significant gains in Questions 3 and 5. Students in public institutions had significant gains from pre-test to the post-test on the total score, Questions 1, 2, 4, 5, 7, 8, and 10. However, students in private institutions did not show significant gains in Questions 3, 6, and 9.

A statistical analysis was conducted on all pre-test and post-test data to detect changes in students' understanding of the geotechnical concepts over the course of the semester. Comparison of the pre- and post-test scores was completed using the paired t-test at five percent level of significance, and the results are shown in Table 2. The difference between the means was statistically significant for each institution and all institutions combined, showing substantial improvement from pre-test to post-test at five percent level of significance. The results showed that there was a significant difference in scores for pre-test and post-test. There was an increase from an average score of 21.6% on the pre-test to an average score of 74.9% on the post-test (mean paired diff = 53.4, SE = 0.433; $t(196) = 40.3$, p-value < 0.001) across all institutions (see Table 2).

Table 2. Pre-test-post-test means, standard deviations, differences of institutions in this study

		Pre-Test		Post-Test				
Program	n	Mean (%)	St Dev (%)	Mean (%)	St Dev (%)	Mean Diff (%)	t	p-value
The CitadelDay-F2014	26	15.3	7.6	82.5	16.0	67.1	22.4	<0.001
The CitadelEve-F2014	20	21.8	14.2	62.0	15.0	40.2	12.0	<0.001
The CitadelDay-F2015	50	15.6	10.5	81.5	15.3	65.9	28.4	<0.001
The CitadelEve-F2015	17	15.6	7.5	69.4	14.6	53.8	19.0	<0.001
Merrimack F-2014	16	40.0	12.4	70.6	14.6	30.6	6.4	<0.001
Merrimack F-2015	25	28.2	12.9	71.0	17.0	42.8	24.0	<0.001
Evansville S-2015	13	16.9	12.2	63.1	13.8	46.2	12.9	<0.001
Virginia Tech F-2015	30	29.2	12.1	80.2	14.0	51.0	17.1	<0.001
All	197	21.6	13.1	74.9	16.7	53.4	40.3	<0.001

The next step in analyzing pre- to post-test gains was to look at changes in correct responses for individual questions. The paired sample t-test was conducted for each question to test for statistically significant differences between pre- and post-test scores. Comparison of the student's performances in public and private institutions showed that all students performed similarly on each question and overall score when measuring conceptual understanding from pre-test to post-test (see Table 3). All ten questions showed a statistically significant difference between the pre- and post-tests (all $p < 0.001$). The comparison of research and teaching-focused institutions showed that the students in the research institution did not show significant gains Question 2, the interpretation of the index properties of soils, with $p > 0.05$ (see Table 3). However, the students at the research institution displayed a higher pre-test score on this question than students at the teaching institutions.

Table 3. Geotechnical concept growth from pre-test to post-test (n = 197)

Measure	All Institutions (df = 196)			Research Institution (df = 29)			Teaching Institutions (df = 166)			Private Institutions (df = 53)			Public Institutions (df = 142)		
	Mean Paired Diff (%)	t	p-value	Mean Paired Diff (%)	t	p-value	Mean Paired Diff (%)	t	p-value	Mean Paired Diff (%)	t	p-value	Mean Paired Diff (%)	t	p-value
Total Score	53.4	40.3	< 0.001	51	17.1	< 0.001	53.8	36.6	< 0.001	41.2	21.9	< 0.001	57.9	38.3	< 0.001
Q1	58.9	17.8	< 0.001	45	5.3	< 0.001	61.4	17.2	< 0.001	61.1	10.4	< 0.001	58.0	14.6	< 0.001
Q2	35.5	9.0	< 0.001	22	1.9	**0.073**	38.0	9.2	< 0.001	26.9	3.9	< 0.001	38.8	8.2	< 0.001
Q3	44.7	12.7	< 0.001	37	4.9	< 0.001	46.1	11.8	< 0.001	15.7	2.8	0.007	55.6	13.9	< 0.001
Q4	77.4	30.3	< 0.001	63	9.4	< 0.001	80.0	29.4	< 0.001	54.6	10.2	< 0.001	86.0	33.7	< 0.001
Q5	20.1	7.7	< 0.001	13	2.5	0.018	21.3	7.3	< 0.001	39.8	7.2	< 0.001	12.6	4.7	< 0.001
Q6	50.3	13.7	< 0.001	65	9.0	< 0.001	47.6	11.6	< 0.001	22.2	3.0	0.004	60.8	15.7	< 0.001
Q7	58.9	17.7	< 0.001	68	8.1	< 0.001	57.2	15.8	< 0.001	42.6	7.3	< 0.001	65.0	16.6	< 0.001
Q8	71.3	22.9	< 0.001	77	10.8	< 0.001	70.4	20.4	< 0.001	33.3	5.5	< 0.001	85.7	30.2	< 0.001
Q9	64.7	18.2	< 0.001	48	5.5	< 0.001	67.7	17.6	< 0.001	25.9	3.6	< 0.001	79.4	23.8	< 0.001
Q10	53	14.6	< 0.001	72	9.2	< 0.001	49.7	12.4	< 0.001	48.1	6.8	< 0.001	54.9	12.9	< 0.001

Suggestions for Future Research

This study indicated several differences between types of universities and associated effects of teaching an introductory class on geotechnical engineering. It examined several important concepts within this topic and evaluated how the course experience affects the knowledge gained by the student body. Further research can potentially elucidate on why students demonstrated significant improvement in certain topics, while not in others. The results of this study may also suggest what instructors can do to ensure equal improvement on all topics. More factors can be investigated and measured such as: class size, laboratory section size and topics covered in prerequisite courses. The future research will also include identifying course characteristics that improve conceptual learning in geotechnical engineering. Continuous administration of the pre- and post-test can reduce any biases (e.g. the test was administered only once at Virginia Tech and Evansville and twice at The Citadel and Merrimack). Student population and diversity (low at The Citadel, but high at Virginia Tech and very low overall as illustrated in Figure 1) can also play a significant role in the results obtained and could further be elucidated. Last but not least, few sources of distinction can be added to better assess the student body, wherein students will need to explicitly report whether they have taken an introductory course in geology.

Conclusions

Using data from four institutions, this study assessed the amount of exposure students have to geotechnical engineering prior to the introductory course. This study also assessed the amount of gains in conceptual understanding of geotechnical topics as a result of various pedagogical techniques used. The following conclusions can be made based on the study results:

- Students are entering the introductory geotechnical engineering course with little prior knowledge. The low performance on several of the pretest questions is not surprising, as students are not expected to have wide exposure to these concepts prior to completing a course in soil mechanics. The results show that there are variations in students' exposure to geotechnical engineering concepts at various institutions prior to their first course in soil mechanics.

- Students' pre-test scores on the Mohr Circle question were lower than expected, despite the fact that a course in mechanics of materials is a prerequisite for geotechnical engineering courses at all the institutions in this study. These low scores suggest that students do not adequately retain Mohr circle concepts between their initial exposure in Mechanics of Materials and the start of their introductory geotechnical engineering course.

- Regardless of institutional pedagogical techniques, students experience significant gains in conceptual understanding of geotechnical concepts during the course. The difference between the means of pre-test and post-test was statistically significant for each institution and all institutions combined, showing improvements from pre-test to post-test. There was an increase from an average percentage correct of 21.6 on the pre-test to an average percentage correct of 74.9 on the post-test across all institutions. The pre-test to post-test changes in overall scores was influenced by the various pedagogical techniques used in all institutions in this study.

- Analysis of the results of the pre-tests and post-tests as a whole showed that there are relatively small differences between public vs. private and research vs. teaching institutions. The relative difference between pre- and post-test means stay constant regardless of the comparison, and standard deviation drops significantly, indicating less scatter in the-admittedly-improved post-test results.

- This research provides a necessary first step towards identifying capabilities and limitations in our capacity in teaching geotechnical engineering and can provide important feedback with regards to what works and what does not work for improving student's conceptual understanding of fundamental concepts. With further refinements and similar continuous investigations, this research can contribute to more informed and intentional teaching, placing an emphasis on the concepts that have been proven to be weakest amongst the students.

References

1. Couttolenc, O. "The Practical Experience of Professors on the Geotechnical Teaching Process", ASCE GEODENVER 2000, Educational Issues in Geotechnical Engineering, Geotechnical Special Publication No. 109, pp. 409-412, 2000.

2. Wesley, L.D. "Challenges of Geotechnical Engineering Education" ASCE GEODENVER 2000, Educational Issues in Geotechnical Engineering, Geotechnical Special Publication No. 109, pp. 241-248, 2000.

3. Sallfors, L.L., and Sallfors, G.B. "Focus on Real Life Problems Facilitating Learning and Understanding", ASCE GEODENVER 2000, Educational Issues in Geotechnical Engineering, Geotechnical Special Publication No. 109, pp. 425-431, 2000.

4. Novak, G.M., Patterson, E.T., Gavrin, A.D., and Christian, W. *Just-in-Time Teaching: Blending Active Learning with Web Technology.* Prentice-Hall, Upper Saddle River, N.J, 1999.

5. Ghanat, S.T., Brannan, K., Welch, R.W., Bower, K. "Comparison of Direct and Indirect Assessment of a Summer Engineering Economy Course taught with Active Learning Techniques" 122nd ASEE Annual Conference & Exposition, Seattle, WA, 2015.

6. Angelo, T.A. and Cross, K.P. *Classroom Assessment Techniques, A Handbook for College Teachers*. 2nd ed, Jossey-Bass Publishers, San Francisco, CA, 1993.

7. Ressler, S.J., Welch, R.W., and Meyer, K.F. "Organizing and Delivering Classroom Instruction," Teaching Lessons Learned. Journal of Professional Issues in Engineering Education and Practice, ASCE 130 (3), pp. 103-120, 2004.

8. Moore, L. S., and Detlaff, A. J. "Using educational games as a form of teaching in social work." *Arete.*,Vol. 29(1), pp. 58-72, 2005.

9. Rotter, K. "Assisted modifying 'Jeopardy!: Games to benefit all students." *Teaching Exceptional Children,* Vol. 36(3), pp. 58-62, 2004.

10. Dorn, D. S. “Simulation games: One more tool on the pedagogical shelf.” *Teaching Sociology*, Vol. 17(1), pp. 1-18, 1989.

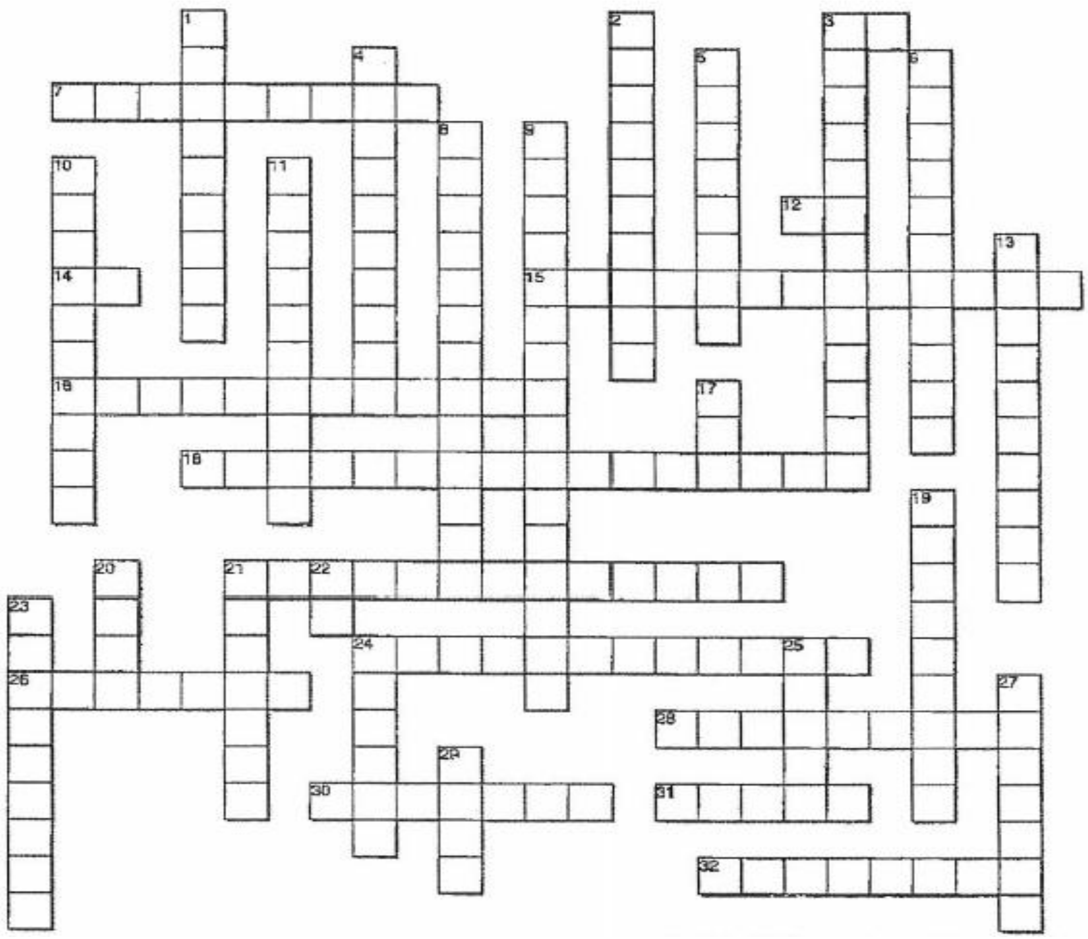
11. Estes, A, C., Welch, R,W., and Ressler, S. J. “The ExCEEd Teaching Model”, Journal of Professional Issues in Engineering Education and Practice 131(4), pp. 218–222, 2005.

12. Cross, T. C., and Kaklamanos, J. “Incorporating Natural Disasters into the Undergraduate Civil Engineering Curriculum: A Case Study of Hurricane Katrina and the Oso Landslide”, 2014 International Conference on Disaster Mitigation, Preparedness, Response, and Sustainable Reconstruction, Boston, MA, 2014.

13. Coduto, D. P., Yeung, M. R., and Kitch, W. A. *Geotechnical Engineering: Principles and Practices*. 2nd ed, Prentice Hall, Upper Saddle River, N.J., 2011.

Appendix A: Learning Games Used at The Citadel

Figure A1. Exam 1 review: game of Jeopardy used at The Citadel



Across

3. USCS high plasticity clay
7. major and minor ________ stresses
12. Elastic Silt
14. USCS Silty Sand
15. water is forced out with increase in stress
16. sands are typically ________
18. maximum past stress
21. settlement in sand
24. Measure of water flow through a soil
26. a soil can achieve its maximum dry density at its ______ moisture content
28. total stress - effective stress. _________ pressure
30. Method for looking at underground water flow
31. sigma tan phi plus c. ______ strength
32. weight of water over weight of solids

Down

1. A common form of montmorillinite
2. strength from particle interaction
3. settlement in clay
4. volume of water over volume of voids
5. strength from electro static forces
6. changes with moisture content. _______ of clay
8. slope of the consolidation rebound line. _____ index
9. used to have a glacier on it
10. The liquid limit - plastic limit is the _______ index
11. A lab test where no consolidation stresses are placed on the sample
13. air forced out by mechanical means
17. A drill rig.
19. volume of voids over volume of solids
20. dry, saturated, and total _____ weight
21. stress from an added load
22. USCS Clayey Sand
23. effective, total stress. pore water pressure.
24. A coarse grained soil where are the particles are the same size is _______ graded
25. Orientation of Failure Plane
27. pore water pressure dissipates faster than rate of loading
29. well graded gravel with clay

Figure A2. Crossword puzzle generated by a student team prior to an exam at The Citadel

Appendix B: Instruction on Mohr Circle methods at The Citadel

Coverage of Mohr Circle in Mechanics of Materials

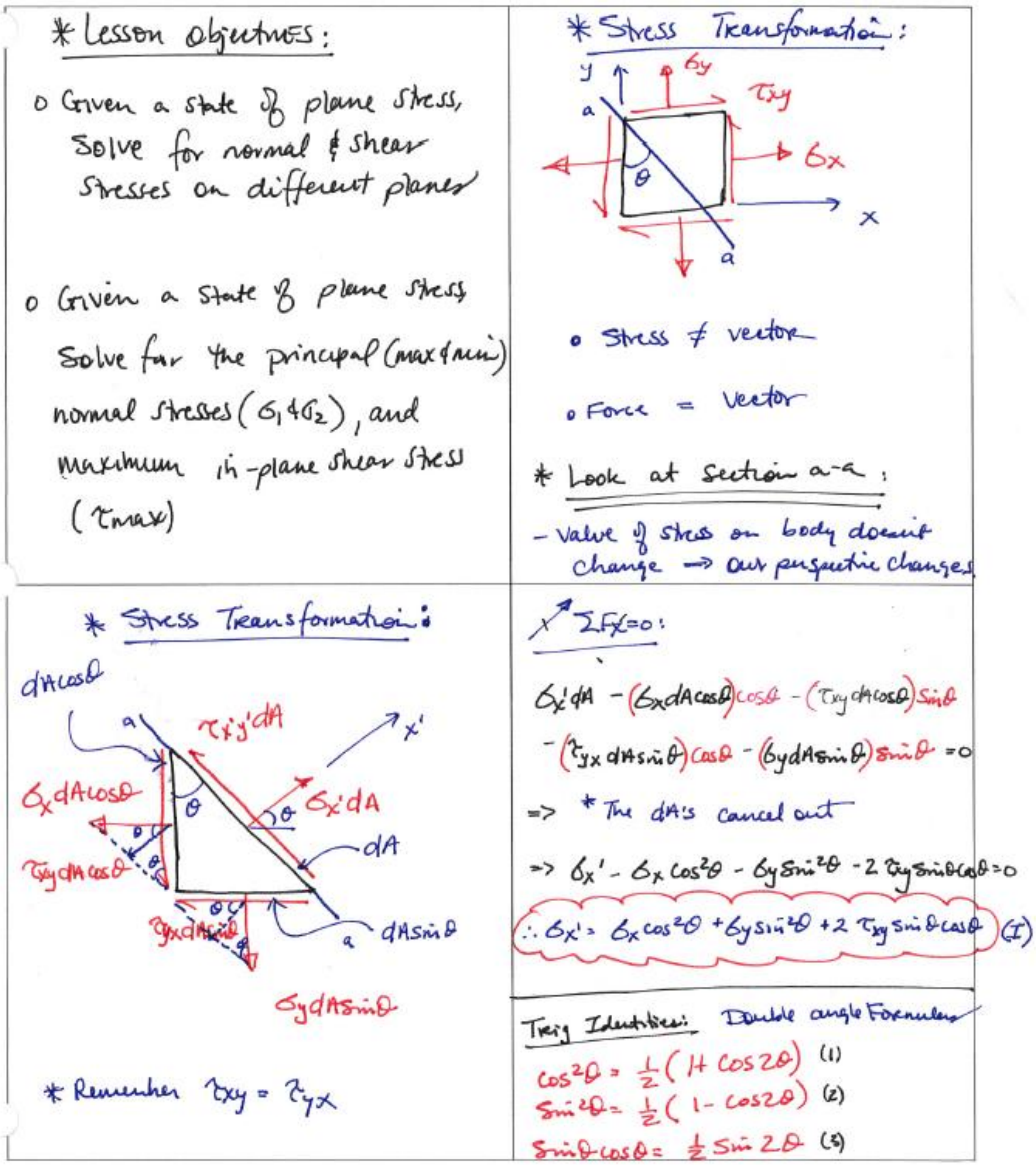


Figure B1. Sample course notes for stress transformation equations used at The Citadel

Coverage of Mohr Circle in Geotechnical Engineering

According to Coduto et al. (2011)[13], since soils and rock rarely experience tensile loads, it is common practice to define compressive stresses as positive, the opposite of structural mechanics. To be consistent, shearing stresses and angular directions are also given an opposite sign convention (Figure B1).

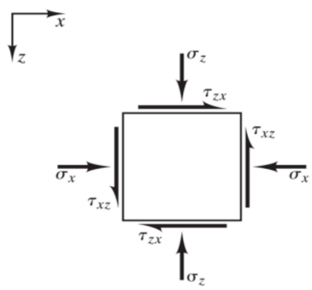


Figure B1. A two-dimensional soil element aligned with the *x*- and *z*-axes (Coduto et al., 2011)

Besides differences in sign convention and notation, there is another major difference in the instruction of Mohr Circle between the two courses: the graphical (pole) method is much more commonly used in geotechnical engineering courses, and is rarely addressed in Mechanics of Materials. Figure B2 displays an example of the pole method:

(a) Points Z and X on the circle represent the stresses for soil element shown in Figure B1;

(b) Locate the pole P;

(c) Determine the principal stresses by drawing lines from the pole to Points 1 and 3;

(d) Determine the stresses on an arbitrary pair of orthogonal planes A and B.

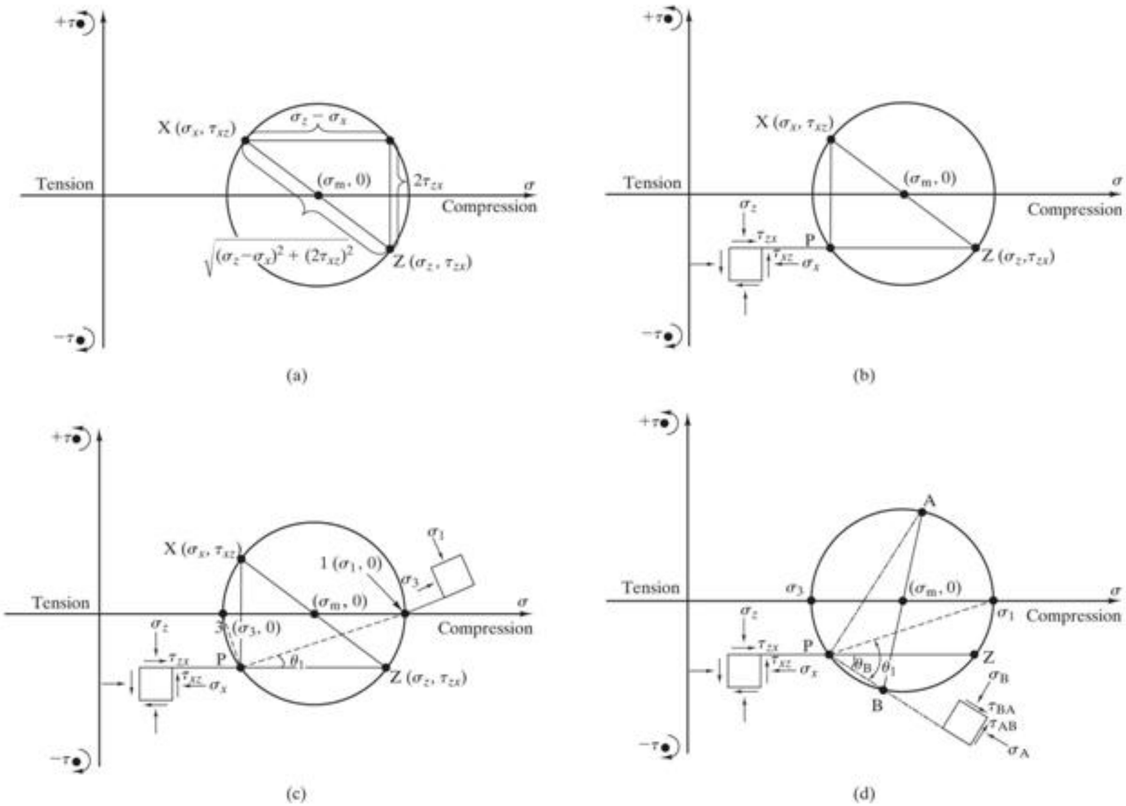


Figure B2. Mohr circle of stress and the pole method (Coduto et al., 2011).