

Assessment of Students' Prior Knowledge and Learning in an Undergraduate Foundation Engineering Course

Dr. Simon Thomas Ghanat P.E., The Citadel

Dr. Simon Ghanat is an Assistant Professor of Civil and Environmental Engineering at The Citadel (Charleston, S.C.). He received his Ph.D., M.S., and B.S. degrees in Civil and Environmental Engineering from Arizona State University. His research interests are in Engineering Education and Geotechnical Earthquake Engineering. He previously taught at Bucknell University and Arizona State University.

Prof. James Kaklamanos, Merrimack College

Dr. James Kaklamanos is Assistant Professor of Civil Engineering at Merrimack College in North Andover, Mass. Prior to joining the Merrimack faculty, Jim completed his Ph.D. in Civil and Environmental Engineering at Tufts University in Medford, Mass. He specializes in geotechnical engineering, and his published work has included research on ground-motion prediction equations, site response analyses, uncertainty in earthquake engineering, and engineering education. At Merrimack, Jim has taught courses in geotechnical engineering, foundation engineering, earth retaining structures, earthquake engineering, engineering mechanics, and engineering probability and statistics.

Dr. Suresh Immanuel Selvaraj, University of Evansville

Dr. Suresh Immanuel Selvaraj is an associate professor of civil engineering at the University of Evansville, IN. He holds a PhD degree from Auburn University and a licensed professional engineer. His research interests are in pavement design and analysis, pavement management, pavement instrumentation and engineering education. At the University of Evansville, he teaches courses such as transportation engineering, soil mechanics, geotechnical engineering, advanced pavement design and management, and surveying.

Dr. Corrie Walton-Macaulay, Bucknell University

With degrees in both Bachelor of Science and Master of Science from the University of Arkansas, and a doctoral degree from the University of Kentucky, Dr. Corrie Walton-Macaulay is now a Geotechnical Engineering Assistant Professor in the Civil and Environmental Engineering Department at Bucknell University. He teaches the traditional geotechnical courses of soil mechanics and foundation engineering, but also teaches unsaturated soil mechanics, introduction to transportation and mechanics of materials. His research area is in unsaturated soil mechanics, energy geotechnics, and transportation infrastructure resiliency.

Address: 1 Dent Drive, Department of Civil and Environmental Engineering, Bucknell University, Lewisburg, PA 17837

Dr. Matthew Sleep, Oregon Institute of Technology

Matthew Sleep is an assistant professor of civil engineering at Oregon Institute of Technology. Prior to Oregon Tech, Matthew received his PhD at Virginia Tech researching slope stability, levees, transient seepage and reliability. Matthew is from Nashville, TN and has worked for the United States Army Corps of Engineers and private consulting. He currently teaches and continues research on reliability and transient seepage.

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Introduction

A commonly accepted assessment instrument used for both diagnostic and formative purposes is the concept inventory¹, which refers to any kind of research-based assessment technique that measures conceptual understanding². The usage of concept inventories helps instructors measure the effectiveness of their teaching² and determines if students have adequate understanding of important concepts on a topic. It has been shown that concept inventories provide reliable data and can positively influence pedagogical practices¹. When the same set of questions is used, concept inventories allow for an evaluation of students' pre-course and post-course knowledge on a subject. Pre-tests establish the prior knowledge on a subject, and post-tests measure the learning at the end of a learning experience³. These types of tests also help distinguish between learning and performance³. In addition, monitoring the results of pre- and post-course concept inventories allow instructors to make comparisons among the effectiveness of their teaching over time and possibly in different environments and across different institutions². Concept inventories are used in a variety of courses¹. Ghanat et al. (2016)⁴ assessed the usage of concept inventories in introductory geotechnical engineering courses. However, there are no studies on using concept inventories to assess pre- and post-course knowledge in upper-level geotechnical engineering courses such as Foundation Engineering. Therefore, this paper focuses on assessing students' pre- and post-course conceptual learning in Foundation Engineering using the widely used and accepted assessment technique of concept inventories.

Most undergraduate Civil Engineering programs in the United States offer at least two courses related to geotechnical engineering; one in soil mechanics and the other in foundation engineering. Typically, students take the soil mechanics course during their junior year, which focuses on soil mechanics and the engineering properties of soils. The foundation engineering course is primarily taken by students in their senior year. This course applies the concepts learned in the first course to the geotechnical analysis and design of foundations.

The primary objective of this multi-institutional study was to assess student learning as a result of the geotechnical curricula and various pedagogical techniques implemented in the foundation engineering courses at these institutions. The study was carried out at four teaching-focused institutions with Civil Engineering programs, all of which are predominantly undergraduate institutions. Three of these universities are private, and the other is 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.
- Bucknell University: small private university in the Northeast U.S.

Pre- and post-course surveys were developed based on key concepts in geotechnical engineering to assess students' prior exposure and knowledge gained in the foundation engineering course. The pre-tests (background knowledge probes) were administered to measure students' prior geotechnical engineering knowledge and to identify student misconceptions at the beginning of

each semester. Background knowledge probes are useful instruments for faculty to assess students' prior learning, and for students to begin to recognize the important course topics and themes to follow⁵. The post-tests (course knowledge surveys) were administered on the last day of the semester to assess knowledge gained as a result of the course experience. The same questions were used on both the background knowledge probe and course knowledge survey, allowing for an assessment of the knowledge gained because of the course experience. Data were collected over the span of two years at The Citadel, Merrimack, and Evansville, and over one year at Bucknell University. This paper discusses the institutional context, geotechnical engineering curricula, instructional techniques used at each institution; the analyses of the pre- and post-test results; and conclusions and suggestions for future research.

Institutional Context and Course Format

The Citadel enrolls approximately 2,300 students in its undergraduate military program and approximately 1,000 students in its undergraduate civilian program. In Civil Engineering, there are approximately 200 undergraduates and 10 graduate students. As a requirement for graduation, Civil Engineering majors must take Geotechnical Engineering II (Foundation Design) in the second semester of their senior year. This course focuses on the analysis and design of foundations. The course is offered as co-requisite to the laboratory portion of the first geotechnical engineering course in both day and evening programs in the spring semester. Day classes meet three times a week (50 minutes each) and are populated by students of traditional age. Evening classes meet twice a week (75 minutes each) and are populated with students who live in the community, many of whom work full or part-time.

Merrimack College is an independent college in the Catholic tradition with undergraduate and master's programs in liberal arts, engineering, business, science, and education. This institution has a total enrollment of approximately 3,800 (3,200 undergraduate and 600 graduate students); 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 with a laboratory component (typically completed during the fall semester of their junior year), and (2) a design elective in geotechnical engineering (either Foundation Engineering or Earth Slopes and Retaining Structures) during their senior year or spring semester of their junior year. Each design course is worth four credits and has two 2-hour meetings per week. Foundation Engineering, offered every fall semester, focuses on the analysis and design of shallow and deep foundations; subsurface investigations are also covered early in the semester. Earth Slopes and Retaining Structures, offered every spring semester, 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. Students have the option of completing either or both courses; based on trends in past years, approximately 50% of civil engineering undergraduates only take Foundation Engineering, 25% take only Earth Slopes and Retaining Structures, and 25% take both courses. The vast majority of students enrolled in the two geotechnical design courses are full-time undergraduates; both courses are also available to master's students, although graduate students usually comprise less than 10–15% of the course enrollment.

The total enrollment at the 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 graduation requirement, 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 Soil Mechanics and Soil Behavior course is offered in the spring semester of the junior year and it primarily focuses on the index and engineering properties of soils, as well as the mechanics of soils. The Geotechnical Engineering course is taken by students in the fall semester of their senior year. The course focuses on the analysis and design of shallow and deep foundations, retaining wall design and slope stability analysis. Subsoil exploration and seismic site characterization are also covered in this course, which meets for two 75-minute lectures per week. The students who take this course are traditional, full time undergraduate Civil Engineering students.

Bucknell University is a private liberal arts university with an engineering program. This institution has an undergraduate enrollment of approximately 3,600 traditional students. Approximately 725 of these students are enrolled in the engineering program, with about a third being female students. Currently, 128 students are enrolled in the Civil and Environmental Engineering program (102 Civil and 26 Environmental). Geotechnical Engineering II: Foundation Engineering is an upper class elective course in the Civil Engineering program. Students' interests in the Geotechnical Engineering II course generally stem from the required Geotechnical Engineering I course (Soil Mechanics), professor-student interactions, and undergraduate research opportunities. Geotechnical Engineering II is offered in the fall semester of every year as a 4-hour credit course. The course is usually scheduled as a 52-minute session, three times a week including a one-hour, 52-minute laboratory session once a week.

Comparisons of Course Curricula

Table 1 displays a cross-comparison of the contents of the Foundation Engineering course at the four institutions used in this study. A few interesting trends are noted. Approximately 80% of the Foundation Design course at The Citadel is dedicated to the site characterization, analysis and design of shallow foundations, deep foundations, and retaining walls. The remainder of the course focuses on the review of soil mechanics concepts, slope stability, foundation construction methods, ground improvement, foundation design concepts, and foundations on problematic soils. The Foundation Engineering course at Merrimack College has considerably less coverage of slope stability, lateral earth pressures, and earth retaining structure design, because these topics are primarily addressed in a separate course (Earth Slopes and Retaining Structures). Greater emphasis is placed on the analysis and design of shallow and deep foundations in the Foundation Engineering course at Merrimack College.

The Bucknell curriculum includes six contact hours of case studies, which involved topics of foundation construction and foundation settlement in the most recent course offering (Fall 2016), but these topics will vary with subsequent course offerings. Several specialized areas of foundation engineering, such as braced excavations, ground improvements and foundations on difficult soils are introduced in this course, as the students have the opportunity to take only one additional geotechnical elective course in which a special area of interest is addressed in depth.

Approximately 55% of the course at the University of Evansville covers subsoil investigation, and analysis and design of foundations. Both spread and mat foundations are covered in the course unit on shallow foundations. In the unit on deep foundations, the main emphasis is placed on analyzing and designing pile foundations. Roughly 40% of the course material covers lateral earth pressure, retaining wall design (gravity and cantilever) and slope stability analysis. Two class hours are utilized to teach a slope stability analysis program to enable students to verify the manual calculations while analyzing the slopes.

Table 1. Comparisons of the Foundation Engineering course curriculum at the four institutions

	The Citadel	Merrimack	Bucknell	Evansville
Course Title	Foundation Design	Foundation Engineering	Geotechnical Engineering II	Geotechnical Engineering
<i>Curricular topic</i>	<i>Class and Laboratory hours devoted to each topic</i>			
Soil mechanics review	1	5	8	1
Site characterization and subsurface investigation	7	6	14	4
Foundation types, construction, and selection (conceptual)	3	5	1	1
Foundation design concepts (ASD, LRFD, etc.)	1	2	1	1
Shallow foundations: analysis and design	9	15	6	10
Deep foundations: analysis and design	9	12	9	7
Slope stability	2	1	0	6
Lateral earth pressures	3	1	2	5
Earth retaining structure design	6	0	7	6
Braced excavations	0	0	4	0
Ground improvements	1	0	2	0
Foundations on difficult soils	0	0	2	0
Case studies	0	3	6	1

Pedagogical Techniques Used at The Citadel

Various active learning techniques were employed at The Citadel to improve student learning of key geotechnical concepts. These included: pre-class reading responses on the course website; in-class hands-on problem solving; a team design project; journaling; minute papers; and a number of other pedagogical techniques.

Web-based pre-class reading responses^{4,6} 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 needs⁶.

Numerous active in-class real world exercises were prepared for students to complete both with peers and the instructor to enhance understanding of lecture content to help them establish the connection between what they learn from the textbook and what they are expected to do in the actual Civil Engineering field. Active in-class exercises guided students in determining the shear strength of soil using field data from the Standard Penetration and Cone Penetration Tests (SPT and CPT, respectively), bearing capacity, settlement of shallow foundations, geotechnical design of shallow foundations, axial capacity of deep foundations, lateral earth pressures, and design of retaining walls. Additionally, a reflection assignment was created to guide students in critically examining what they have learned and where they feel they need to concentrate their efforts. Real-world homework assignments directly linked to the course learning objectives were devised to scaffold student understanding of the key geotechnical concepts.

To further deepen the understanding of the geotechnical engineering concepts and help with the development of teamwork and leadership skills, students were asked to design an appropriate foundation system for a proposed two-story steel frame building structure on campus. Students were divided into teams of five, and teams were selected based upon overall academic competence and learning styles. Two local geotechnical firms were invited to campus by the course instructor to demonstrate SPT and CPT testing to the students at the proposed site. The firms demonstrated in-situ field testing and soil sampling to the teams and provided teams with boring logs, disturbed soil samples from various depths, and an undisturbed sample from a stiff and cohesive calcareous soil layer. Next, teams were asked to synthesize the subsurface soil data and perform the necessary laboratory experiments to determine properties of soils (i.e., shear strength parameters, unit weight, consolidation properties, classification of soils, etc.). Teams were provided with the overall dimensions of building, the allowable loads for both interior and exterior columns, and the allowable total and differential settlements. The project offered several opportunities for active student learning. It not only required the students to draw upon principles of bearing capacity, settlement, and site characterization, it also required students to conduct experiments to determine properties for use in their design calculations. The teamwork component of the project was 25% of the project grade based on a peer evaluation form⁷, which asked all team members to rate each other on a nine-level scale: (Excellent, Very Good, Satisfactory, Ordinary, Marginal, Deficient, Unsatisfactory, Superficial, and No-show). These measures of performance were converted to a numerical scale (i.e., Excellent = 9, No-Show = 0). Lastly, teams were asked to write a geotechnical design report, which provided them an excellent opportunity to develop their communications skills.

To encourage students to think about the material in greater detail and provide a good opportunity to integrate what they were being taught into other areas, students were asked to keep a weekly journal. They were asked to reflect on each exam, project, and weekly assignments. At the end of each lesson, the One-Minute Paper⁵ 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 seconds⁴.

Pedagogical Techniques Used at Merrimack College

A number of pedagogical techniques were employed at Merrimack College to enhance students' learning of geotechnical and foundation engineering concepts, similar to the other institutions in this study. The instructor has attended 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 Model⁸ 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 whiteboard, with daily outlines and handouts provided to supplement the board notes. In addition, physical demonstrations and slideshows of geotechnical engineering phenomena supplement the whiteboard instruction.

The instructor frequently applies active learning techniques (e.g., questioning, group exercises) to enhance students' interaction in the classroom. Class sessions at Merrimack College are two hours in length, and therefore it is critical to incorporate active learning techniques in order to maintain students' attention throughout the entire session. Throughout the semester, a large number of historical and current events are used to illustrate geotechnical engineering concepts, and the consequences of failures in foundation design. Beyond the Leaning Tower of Pisa, used universally as a historic example of the implications of improper foundation design, the instructor has sought out a number of current events related to foundation engineering. In fall 2016, for example, the excessive settlement of Millennium Tower in San Francisco was frequently discussed in class, as it often appeared in the news.

Assessment of students' learning is achieved via weekly homework assignments, three examinations (two midterms and a final), and two design projects. Homework assignments are intended to develop students' proficiency using the methods covered in class and in the textbook, and include reading questions, case histories, and analysis and design problems. A few interesting homework problems will be mentioned here. As part of the first homework assignment, students are required to read and reflect upon *Underground* by Macaulay (1976)⁹. This intricately illustrated book provides students with a conceptual understanding of foundations and the complex underground network that lies beneath cities. Later in the semester, students undertake a case study of foundation engineering in the Boston, Massachusetts, basin. From a geotechnical engineering perspective, Boston presents a number of unique challenges, including large areas of artificial fill and organics, a fluctuating groundwater table, the presence of Boston Blue Clay (which becomes weaker with depth, and has variable thickness throughout the basin), and the effects of glaciation^{10,11,12}. Students read and analyze two papers on foundation engineering concepts and challenges in Boston^{11,12}, and they select their favorite Boston skyscraper to further investigate (by reporting on that building's foundation design, and any geotechnical challenges during design and construction). This assignment helps to build students' understanding of foundation selection and design, and the recognition that foundation engineering is an art as well as a science.

Besides these homework assignments, the culminating design experience of the semester takes place via two design projects, frequently indicated by students as their favorite part of the course. A campus construction project (an arts center and auditorium) adjacent to the engineering

building serves as the basis for the two geotechnical design project submissions. The first project submission is a subsurface investigation report that involves the analysis of subsurface conditions based upon field data (a series of boring logs), development of a one-dimensional soil profile and properties, recommendations for further laboratory and field testing, and a conceptual foundation design. The second project submission is a geotechnical design report that involves a detailed foundation design for the structure (considering bearing capacity and settlement), using specified structural loads and the geotechnical parameters determined in the first project. Students are at first sometimes apprehensive of the open-ended nature of the design project (compared to some homework problems that are more clearly framed from the outset), but grow to appreciate the higher-level intuition required by such a task, which much more accurately replicates the geotechnical engineering process in professional practice.

Pedagogical Techniques Used at the University of Evansville

Many active learning techniques, such as in-class problem solving sessions, project-based learning, and visual learning were used in the teaching of geotechnical engineering at the University of Evansville. According to various studies conducted in the past, it is clearly known that the majority of engineering students are auditory or visual learners^{13,14}. Considering this, many short-to-medium-length videos were shown to the students at various points in the semester to reinforce certain concepts. Short videos were generally two to four minutes in length. Medium length videos were typically fifteen to twenty minutes in length. Two videos were on subsoil exploration, seven on foundations, four on slope stability and landslides, two on gravity and mechanically stabilized earth (MSE) walls, and two on liquefaction and seismic testing. Periodic feedback was collected to see if the students had any difficulties in understanding the course content. Students were asked to complete weekly homework assignments, and their understanding on the subject was tested using quizzes after the completion of each chapter. A few class periods were designated for in-class group problem solving. Students also completed a slope stability analysis project as a two-member team project. Peer evaluations were used to determine the team members' contribution to the submitted work. Geotechnical data from two projects completed at the campus were used to discuss boring logs, SPT procedures, and other test results to reinforce the technical content. The Indiana Department of Transportation geotechnical manual was used in conjunction with the textbook to apply the concepts and theories to local conditions. The geotechnical engineering content pages from the Fundamentals of Engineering Exam Reference Handbook were allowed for quizzes and exams. The grade in this course was based on student performance on the homework assignments, quizzes, design project, and three exams.

Pedagogical Techniques Used at Bucknell University

A mix of both deductive and inductive approaches to teaching was employed in the Foundation Design course at Bucknell University. The deductive approach is more of a traditional engineering instruction and the inductive approach includes alternative methods. Inductive methods create a need-to-know-more by introducing specific observations, case studies, or problems, and after this need to know arises, the students are helped to discover the theories or taught the theories¹⁵. Two inductive approaches to teaching and learning employed this past fall are problem-based learning and case-based learning. In addition, active learning techniques or

structures were incorporated in the lectures to enhance learning. Most of the active learning techniques/structures were centered on think-pair-share, in-lab teams, muddiest (or clearest) point, and the Conceptest¹⁶. The Conceptest technique, short conceptual questions on subject being discussed, was used once in the semester, and with a slight variation that included simultaneous audible voice polling instead of “clickers” or online polling.

The students were eager to use a current proposed new academic building project on campus to define their problem-based learning. This proposed on-campus building would expand the classroom and laboratory spaces for the College of Engineering. The defined “problems” were specific to the class modules for boring logs, site characterization, shallow foundation design, and deep foundation design (piles and drilled-shafts). The geotechnical company retained for the proposed new on-campus building provided the students with all the soil samples obtained from one of the borings. The students were expected to present their findings, design analyses, and solution or recommendations as necessary for the defined “problem.” The case-based learning modules included a settlement design and monitoring study centered on the San Jacinto monument in Houston, Texas, and also included construction-based real recorded events of inspection or observation of the installation of drilled shaft deep foundations. The idea was to develop analytical thinking skills in the design case-based study, and to develop reflective, and sometimes, ethical judgement in the construction case-based studies.

Some of the laboratory sessions were used to discuss case-based learning studies and other laboratory sessions provided the students with a hands-on approach to geotechnical methods employed in the industry for subsurface investigation and laboratory testing. Students were part of a subsurface investigation using Bucknell’s drilling rig in which they planned, obtained field samples, and performed laboratory testing necessary for design. These efforts provided the means for discussion of the laboratory modules for sub-surface sampling, and pertinent laboratory testing. Students also used the laboratory section to participate in a design and construction of sheet pile walls, similar to the ASCE regional and national GeoWall competitions. Class modules that supported the sheet pile wall design in the laboratory were lateral earth pressures and retaining walls.

Other pedagogical techniques employed for this course include a field trip and a guest speaker. The field trip was a visit to a construction site where foundations were being installed. The guest speaker was an alumnus in the geotechnical engineering field, who discussed with the students some of the special projects that he had been involved with, some of the problems encountered, and the solutions they implemented. Assessment was accomplished through student participation, design- and concept-assignments, laboratory assignments, and exams. A mid-term exam and a final exam were scheduled in this course. The mid-term exam was a two-hour exam and the students were given a maximum of three hours to complete the exam. The final exam was a week-long “take-home” exam, with mostly design problems. The final exam constituted 35 percent of the student’s grade.

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 describes the guiding research question for this study:

What do students gain in conceptual understanding about specific foundation engineering topics throughout the semester at various institutions?

Assessment Measure

A ten-question background knowledge probe (pre-test) and course knowledge survey (post-test) were developed based upon fundamental concepts in geotechnical engineering (see Table 2). The pre-tests were administered to measure students' prior geotechnical engineering knowledge and to identify student misconceptions at the beginning of each semester in the foundation engineering course. The same short-answer test was administered on the last day of the semester to assess knowledge gained as a result of the foundation engineering course experience. Each instructor scored his own students against an established correct answer. When grading the pre- and post-test instruments, instructors were looking for key words and phrases. 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 measurable knowledge regarding geotechnical engineering concepts.

Table 2. Pre- and Post-test Survey

Q1	Explain the difference between normally consolidated and over-consolidated clay.
Q2	Explain the differences between compaction and consolidation.
Q3	Explain the difference between the drained and undrained conditions.
Q4	Explain the difference between γ_s and γ_d .
Q5	What information is needed for geotechnical design?
Q6	Why do we need to assess the shear strength of soil?
Q7	You are designing a foundation on sandy/gravelly soils. What type of shear strength analysis do you need to perform? Explain.
Q8	You have been asked to prepare two specimens of Ottawa sands; one of void ratio 0.4 (relatively low void ratio) and other of void ratio of about 0.8 (relatively high void ratio). Explain how sand can be manipulated to achieve these void ratios.
Q9	Consider two slopes, one with soil of liquid limit 30%, and the other with soil of liquid limit 40%. Assuming all other factors to be equal, which slope will fail first? Explain.
Q10	Explain why assessment of groundwater conditions is an important part of foundation engineering.

Results and Discussion

Figure 1 illustrates the means and standard deviations of the overall scores on the pre and post-test across the institutions in this study. Across the four institutions, the pretest means and

standard deviations range from 27% to 57% and 16.2% to 18.2%, respectively. The post-test means and standard deviations range from 64% to 81% and 14.1% to 24.5%, respectively. When analyzing the results of the pre-tests and post-tests as a whole, there are relatively small differences between public vs. private institutions (Figure 2). The relative difference between the pre- and post-test means stay constant regardless of the comparison. There was also noticeably low variation among the different institutions' pre-test standard deviations, although there was slightly greater variation in the post-test standard deviations.

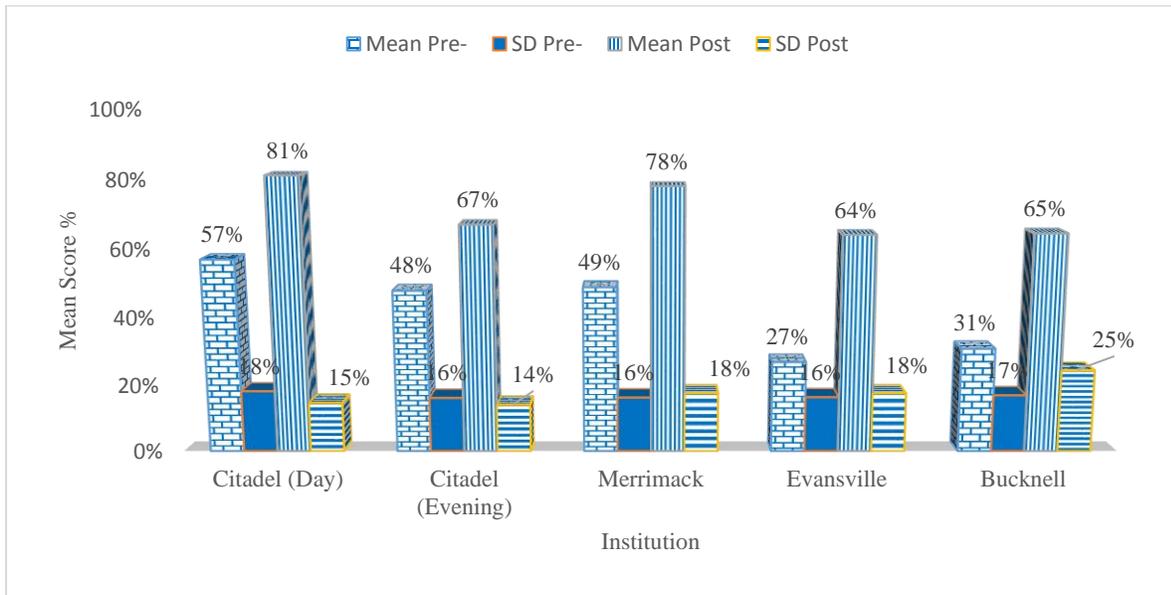


Figure 1. Pre-test and post-test mean and standard deviation for each institution in this study

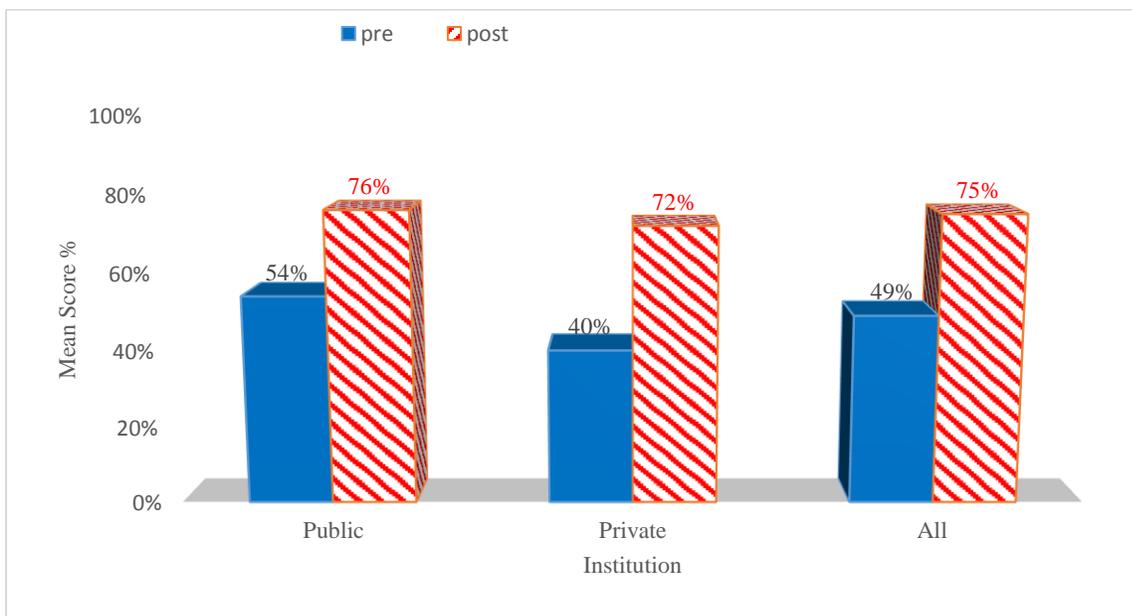


Figure 2. Pre-test and post-test mean for public and private institutions in this study

Figure 3 further analyzes students' performance on each question on the pre-test and post-test. Student performance (at below 50% level) on Questions 1, 4, 7, and 8 of the pre-test is considered poor performance, indicating little to no prior experience with these concepts. The strongest scores on the pre-test were Questions 5 and 6 (assessing information needed for geotechnical design and the importance of shear strength, respectively), which are important themes in the first course in geotechnical engineering that the students successfully retained. The weakest scores on the pre-test were Questions 1 (normally consolidated vs. over-consolidated clay), 4 (unit weights), 7 (type of shear strength analysis needed), and 8 (concepts related to void ratio). Questions 1, 4, and 8 were covered in the first course in geotechnical engineering (suggesting students did not retain these concepts), and Question 7 may have had low scores due to confusion in the question. The scores increased on all of these questions for the post-test, although the scores for Question 7 were still slightly low.

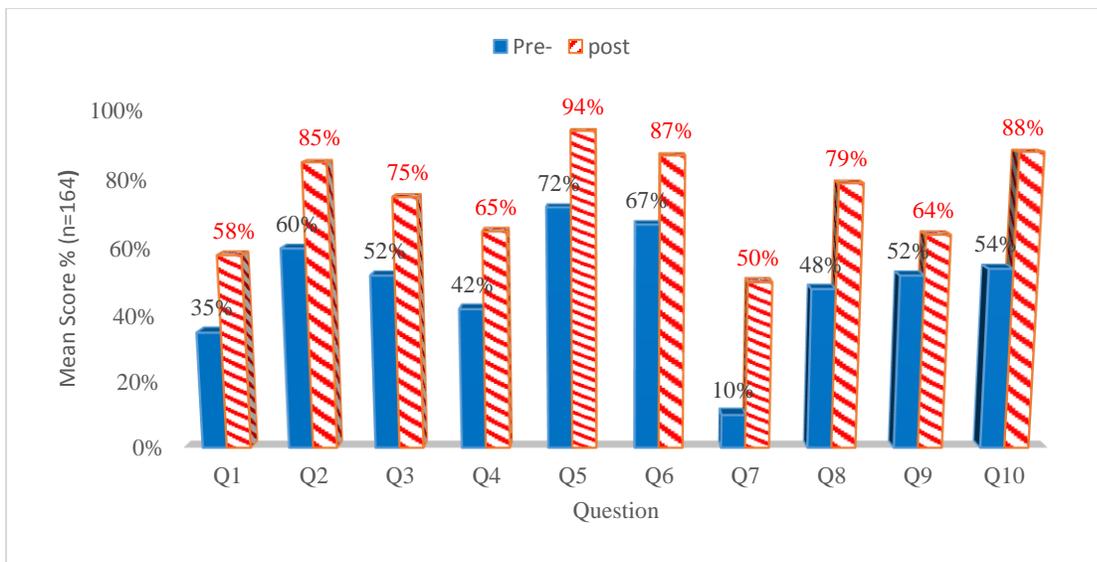


Figure 3. Mean score for each question on the pre- and post-test

The strongest scores on the post-test were Questions 2, 5, 6, and 10 (near-perfect for nearly all students); these questions were all fundamental course concepts that are highly emphasized throughout the semester: compaction vs. consolidation, information needed for geotechnical design, importance of shear strength, and importance of groundwater, respectively. The weakest scores on the post-test were Question 7 (type of shear strength analysis) and Question 9 (slope stability and liquid limit concepts). There was no significant change in students' scores on Question 9 between the pre-test and post-test, perhaps because material regarding slope stability was covered to a very minimal degree in the second course in geotechnical engineering, at least at some institutions. However, this question did involve concepts from both the first and second courses in geotechnical engineering, and requires considerably higher-level cognition. The question is framed as a slope stability question, but is actually assessing students' understanding of the Atterberg limits and their relationship to shear strength. The liquid limit of a soil is the moisture content at which the soil behaves like a liquid (and hence would fail on a slope); as the liquid limit increases, the soil requires more water to reach its liquid state. Therefore, the slope with the lower liquid limit would fail first. One key statement in this question is that *all other*

factors are considered equal; some students did not explicitly consider this statement, and drew their conclusion based on the observations that soils with higher liquid limits often possess lower Mohr-Coulomb strength parameters.

Students performed poorly on both the pre-test and post-test on Questions 1, 4, 7, and 9. This suggests that students have a poor understanding of normally consolidated vs. over-consolidated clay, dry unit weight vs. unit weight of solids, type of shear strength analysis, and slope stability concepts. Mean scores of 35% on the pre-test and 58% on the post-test for Question 1 revealed significant misconceptions about normally and over-consolidated soils. The students understood that normally consolidated vs. over-consolidated soils describe the relationships between pre-consolidation, current and final stresses applied to the soil, but failed to match the correct relationship to the correct condition. As for Question 4, many students incorrectly identified γ_s as the saturated unit weight instead of the unit weight of solids. Figure 4 (see appendix) illustrates the pre- and post-test results for Question #1 at each institution. Questions 4, 7, and 9 deal with unit weights, type of shear strength analysis (drained vs. undrained, etc.), interpretation of liquid limit of soil, all topics normally covered in the prerequisite course. Figure 5 (see appendix) shows the results of the pre- and post-test results for Question #7 across all institutions in this study. The mean pre-test score for all participants was 11%, and the mean post-test score for all participants was 48% (as shown in Figure 3). The majority of students in this study entered and exited the course with a poor understanding of the type of shear strength analysis needed. In addition, this may suggest that the current approaches to instruction are not adequate to produce conceptual change regarding this topic. Figure 6 (see appendix) displays the results for Question 9 on slope stability, and indicates that there is very little change in the pre-test and post-test scores across most institutions. The strong performance on Question 6 (see appendix) indicates that students enter and exit this course with an understanding of the importance of shear strength in geotechnical design (despite perhaps struggling with the type of shear strength analysis necessary). Students across all institutions performed strong on Question 5, the information needed for geotechnical design (see appendix).

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. Comparisons of the pre- and post-test scores were completed using the paired t-test at the five percent level of significance, and the results are shown in Table 3. 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 the 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 49% on the pre-test to an average score of 75% on the post-test (mean paired difference = 26, $t(164) = 16.7$, $p\text{-value} < 0.001$) across all institutions (see Table 3).

Some of the question-specific differences in the institutions may be attributed to variations in the institutions' organizations of geotechnical curricula. Students at the Citadel benefited from taking the laboratory portion of Geotechnical Engineering I course as a co-requisite to Foundation Design. Students were exposed to concepts such as compaction, consolidation, drained and undrained conditions, void ratio, and Atterberg limits, which had an impact on their pre- and post-test performances. In addition, taking Foundation Design immediately after

completion of the Geotechnical Engineering I assisted students with retention of most of the concepts. Geotechnical Engineering I and II are offered in the Fall at both Merrimack and Bucknell. Therefore, students experience an eight-month gap from the end of the first geotechnical engineering course before the start of the second geotechnical engineering course. Time may have been a factor in students' pre-test scores.

Table 3. Pre-test and post-test means, standard deviations, and differences at the institutions in this study

Program/ year	n	Pre-Test		Post-Test		Mean Diff (%)	t	p-value
		Mean (%)	St Dev (%)	Mean (%)	St Dev (%)			
Citadel (Day) (2015-16)	69	57	18.2	81	14.7	24	14.02	<0.001
Citadel (Evening) (2015-16)	40	48	16.2	67	14.1	19	8.6	<0.001
Merrimack (2015-16)	32	49	16.3	78	17.6	29	9.48	<0.001
Evansville (2015-16)	17	27	16.4	64.1	17.6	37.1	8.7	<0.001
Bucknell (2016)	6	31	16.5	64.5	24.5	33.5	4.3	<0.001
All	164	49	16.8	75	20.5	26	16.7	<0.001

Another factor for the variations in the scores is the organization of course content in the second geotechnical engineering course. Table 1 displays some considerable differences in terms of how the second geotechnical engineering course is framed. The Citadel and Merrimack call the second geotechnical engineering course "Foundation Engineering/Design" (implying course content focused on foundation engineering), and Bucknell and Evansville call the second geotechnical engineering course "Geotechnical Engineering / Geotechnical Engineering II" (implying course content focused on a range of geotechnical engineering topics [including foundations]). For example, there was minimal coverage of slope stability and earth retaining structure design at Merrimack in the Foundation Engineering course, as this material is covered in a separate geotechnical design elective. There was also considerable variation in the degree to which subsurface investigations were covered at various institutions.

The paired sample t-test was also conducted for each question to test for statistically significant differences between the pre- and post-test scores. Comparison of the student's performances in across all institutions showed that all students performed similarly on each question and overall score when measuring conceptual understanding from pre-test to post-test. All ten questions showed a statistically significant difference between the pre- and post-tests (all having p-values less than 0.001).

At all institutions, regardless of the particular pedagogical techniques employed, students experience significant gains in conceptual understanding of geotechnical engineering concepts

during the course. Across all institutions, the average score increased by 26% between the pre-test and post-test (increasing from 49% to 75% on average), and the rate of increase was similar across the four institutions in this study. The consistent increases in students' scores provide evidence that the pedagogical techniques are successfully working to improve students' comprehension of foundation engineering concepts. It is difficult to decipher which particular pedagogical techniques were most effective, because the tests represented a snapshot of students' understanding at the beginning and end of the semester; in between, an entire semester's worth of activities have taken place. That said, the instructors' collective approaches of high student-faculty interaction, active learning, real-world design projects, and frequent assessments seem to foster students' learning in geotechnical engineering.

Conclusions:

Using data from four institutions, this study 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:

- The results show that there are variations in students' exposure to geotechnical engineering concepts at various institutions prior to their foundation design course, perhaps owing to variations in how the geotechnical engineering curricula are organized at these institutions.
- Students' pre-test scores on questions regarding the difference between normally and over-consolidated clay, difference between γ_s (unit weight of solids) and γ_d (dry unit weight), type of shear strength analysis, and liquid limit concepts were lower than expected, despite the fact that most of these concepts are covered in the prerequisite course at all the institutions in this study. These low scores suggest that students do not adequately retain these concepts in their introductory geotechnical engineering course.
- Regardless of the 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 49% on the pre-test to an average percentage correct of 75% on the post-test across all institutions. The pre-test to post-test changes in overall scores were 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 institutions. The relative difference between pre- and post-test means stay constant regardless of the comparison. There are more significant differences, however, in terms of the manner in which foundation engineering courses are offered at these institutions (e.g., including the design of foundations and earth retaining structures in the same course vs. separate courses).

This research provides a necessary first step towards identifying capabilities and limitations in our capacity in teaching foundation design and can provide important feedback with regards to

what works and what does not work for improving student's conceptual understanding of fundamental concepts. There is considerably less consensus across institutions with regards to curricula for the second course in geotechnical engineering (covering topics in foundation design) compared to the first course in geotechnical engineering (covering topics in soil mechanics). It is hoped that this study will help begin a dialogue on geotechnical design curricula across institutions. The pre- and post-course concept inventory approach could also be generalized to other civil engineering sub-disciplines. 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.

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Appendix

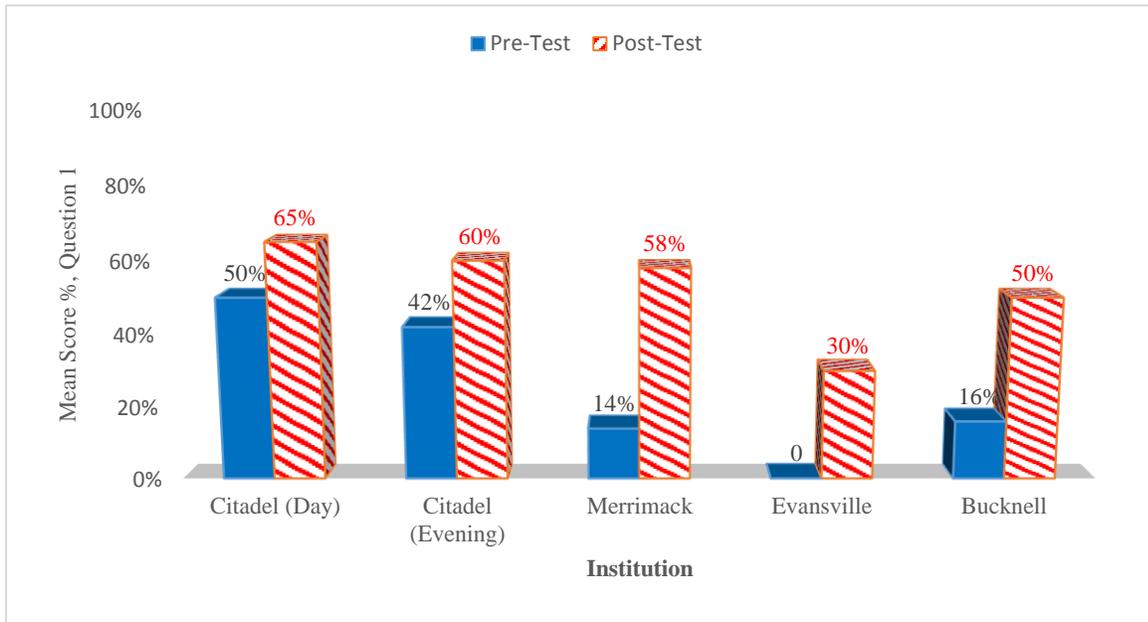


Figure 4. Results of pre-test and post-test for Question 1 (Explain the difference between normally consolidated and over-consolidated clay).

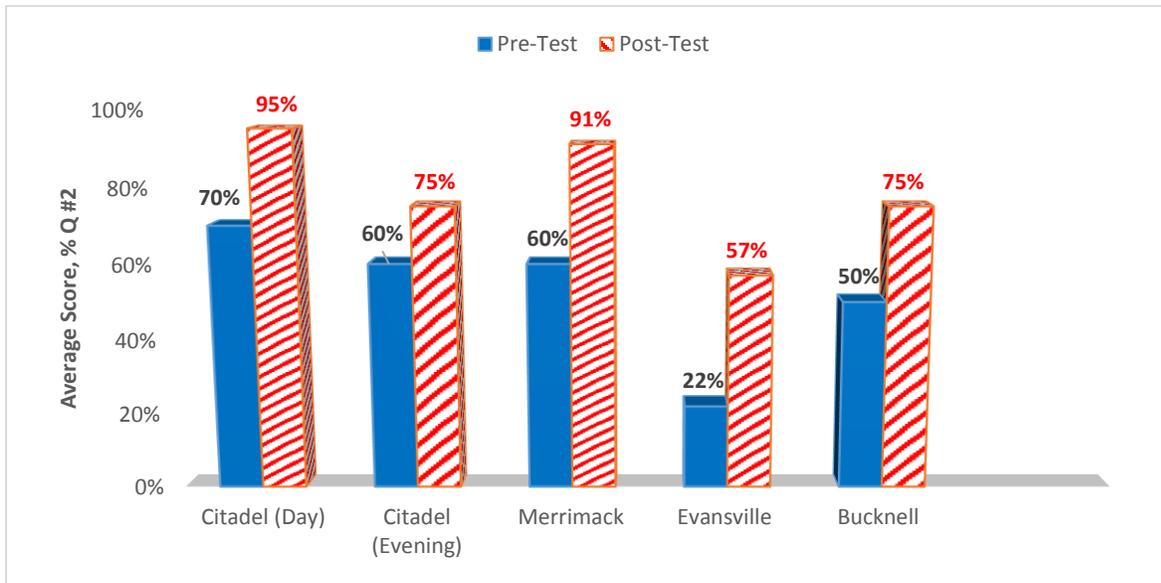


Figure 5. Results of pre-test and post-test for Question 2 (Explain the differences between compaction and consolidation).

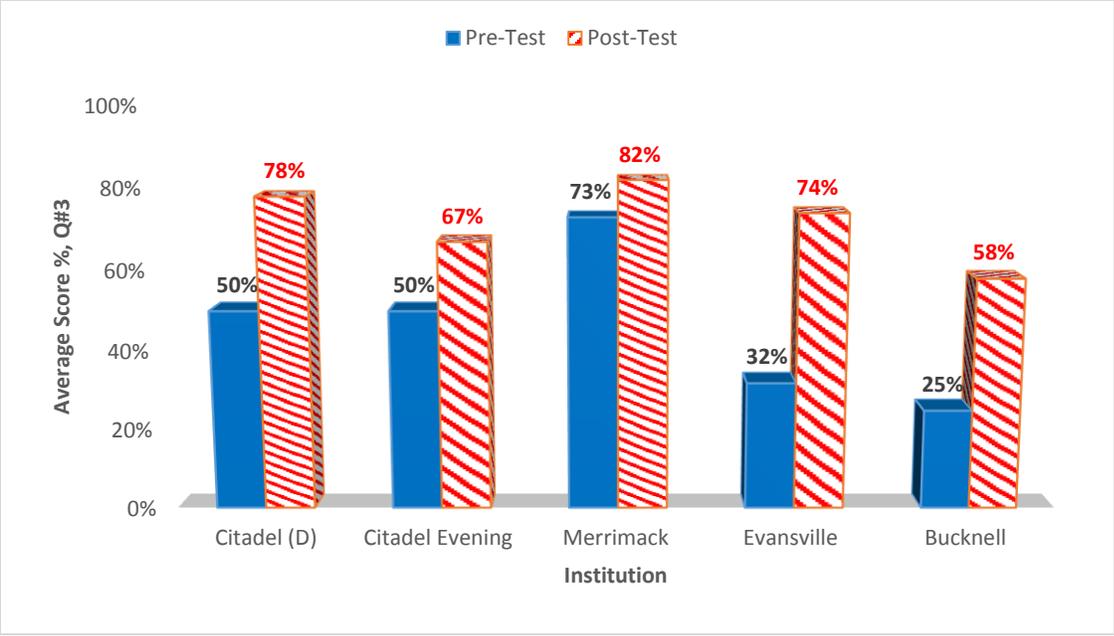


Figure 6. Results of pre-test and post-test for Question 3 (Explain the difference between the drained and undrained conditions).

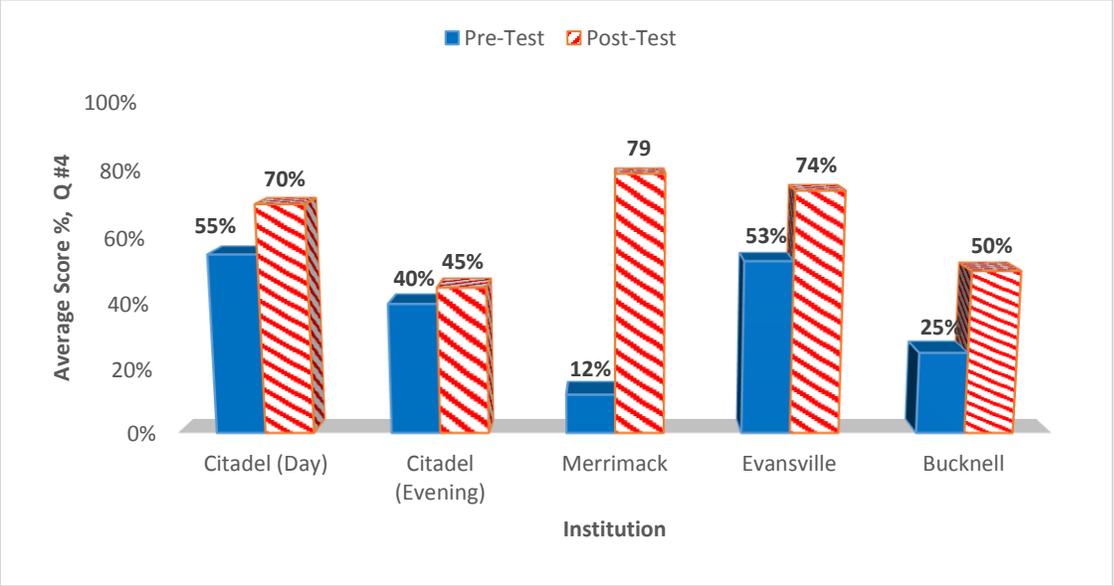


Figure 7. Results of pre-test and post-test for Question 4 (Explain the difference between γ_s and γ_d).

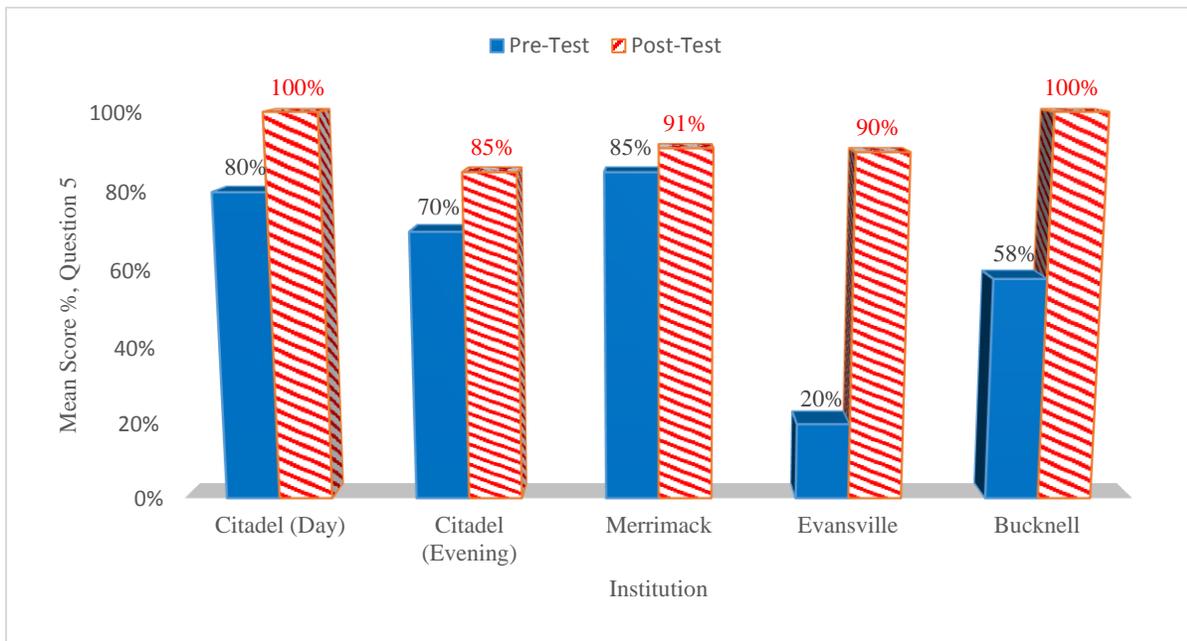


Figure 8. Results of pre-test and post-test for Question 5 (Information needed for geotechnical design).

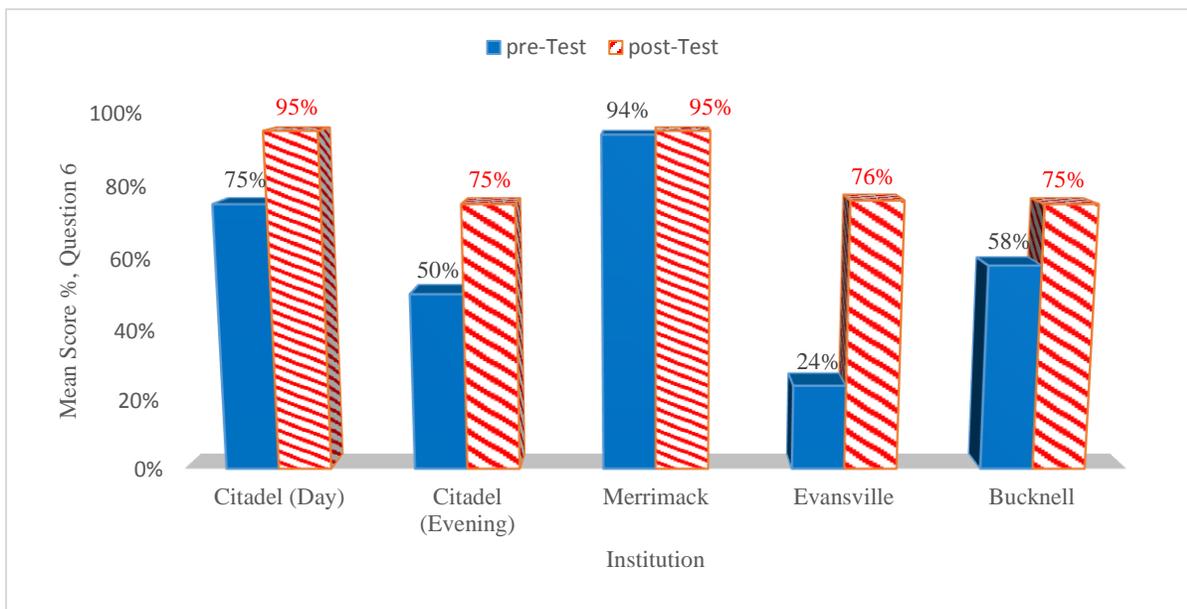


Figure 9. Results of pre-test and post-test for Question 6 (Importance of assessing shear strength of soil).

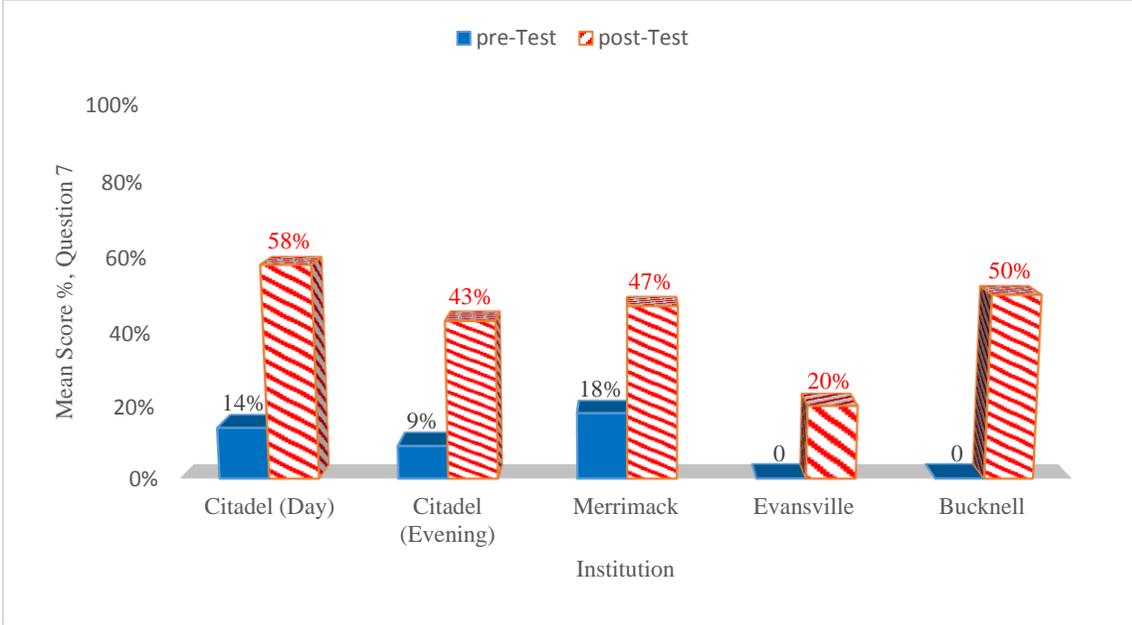


Figure 10. Results of pre-test and post-test for Question 7 (Types of shear strength analysis).

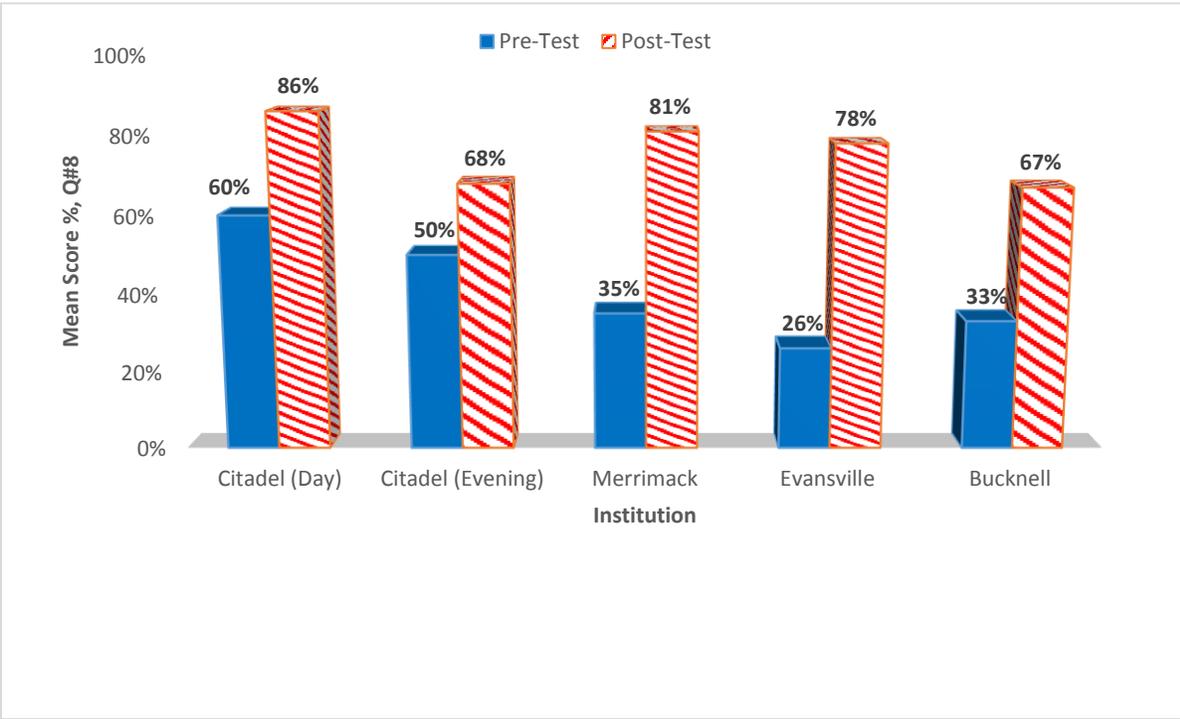


Figure 11. Results of pre-test and post-test for Question 8 (Concepts related to void ratio).

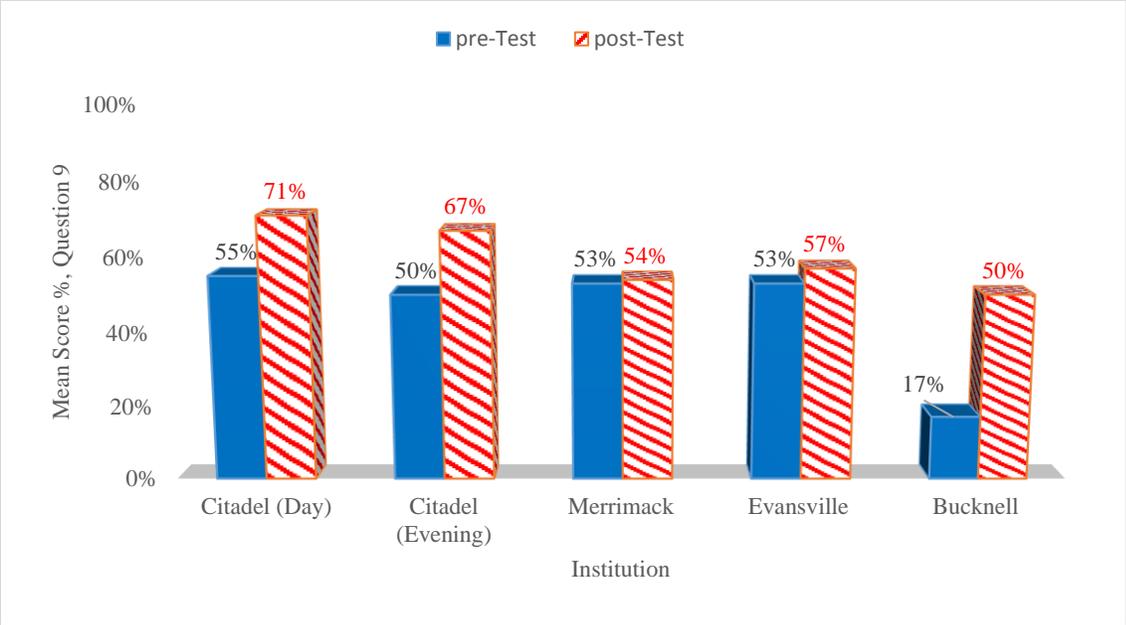


Figure 12. Results of pre-test and post-test for Question 9 (Slope stability).

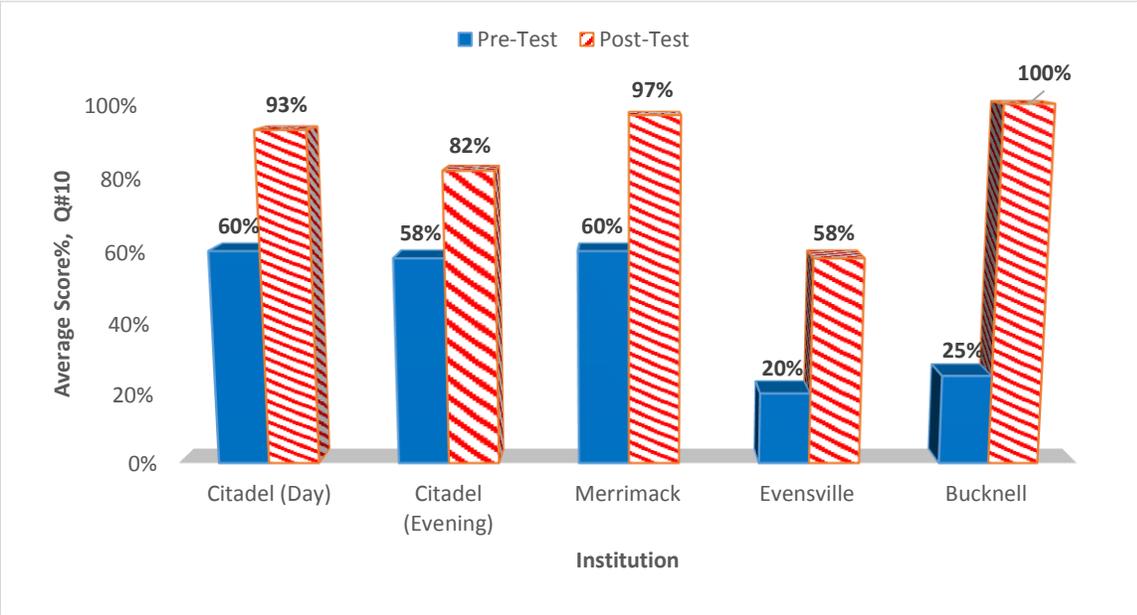


Figure 13. Results of pre-test and post-test for Question 10 (Importance of assessment of groundwater conditions).