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Assessing the Impact of Educational Factors on Conceptual Understanding of Geotechnical Engineering Topics

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Assessing the Impact of Educational Factors on Conceptual Understanding of Geotechnical Engineering Topics

Introduction

A commonly accepted assessment instrument used for both diagnostic and formative purposes is the concept inventory [1], [2], which refers to any kind of research-based assessment technique that measures conceptual understanding [1], [3]. The usage of concept inventories helps instructors measure the effectiveness of their teaching [1], [3] and determines if students have the correct understanding of important concepts on a topic. When the same set of questions is used, concept inventories may help in evaluating students' pre- and post-knowledge on a subject. Pre-tests (sometimes called "background knowledge probes") establish students' prior knowledge on a subject, and post-tests measure the learning at the end of the educational experience [1], [4]. These types of tests also help distinguish between learning and performance [3]. In addition, monitoring the results of pre- and post-concept inventories allow instructors to make comparisons among the effectiveness of their teaching over time and possibly in different environments and across different institutions [1], [3].

Ghanat et al. [5] assessed the usage of pre- and post-course concept inventories in introductory geotechnical engineering courses in a multi-institutional study. They studied the amount of exposure to geotechnical engineering prior to the introductory course, as well as the student learning of specific course topics, as a result of various pedagogical techniques used at the institutions. Ghanat et al. [5] found that students enter the introductory course with little prior knowledge in geotechnical engineering and regardless of institutional pedagogical techniques, students experience significant gains throughout the course. In a follow-up study at multiple institutions, Ghanat et al. [1] performed an assessment using a similar instrument in a second geotechnical engineering course (focusing on the geotechnical design of foundations).

Although there is a perception that smaller class sizes and teaching-focused institutions may foster greater student learning (relative to larger class sizes and institutions that are less focused on undergraduate education), the actual effects of class size and institution type on student learning have been found to be mixed in a number of studies. Several studies have suggested that smaller classes are linked to stronger learning outcomes [6]-[10]. However, Williams et al. [11] and Karakaya et al. [12] found that students perform academically as well in larger university classes, and class size has no impact on student overall grades, respectively. Hattie [13] and Pedder [14] found similar results at the primary and secondary school levels: that class size does not significantly alter student performance. However, Allendoerfer et al. [15] found that student perceptions of faculty support are significantly influenced by class size and institution type. Astin [16] noted that institution type does not have a strong influence on the effectiveness of undergraduate education, but that the environment created by faculty and students plays a stronger role.

The purpose of this study is to examine several educational factors (i.e., institution type, class size, class meeting time, class length and format, laboratory format, and faculty attributes) that may correlate with the amount of knowledge gained in the conceptual understanding of geotechnical engineering topics. The study was carried out at six institutions with civil engineering programs: The Citadel, Merrimack College, University of Evansville, Bucknell University, University of Minnesota Duluth, and Tufts University.

A background knowledge probe (pre-test) and course knowledge survey (post-test) were developed based on fundamental 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 engineering 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 four years at The Citadel and Merrimack College; over two years at the University of Evansville; and over one year at Bucknell, Tufts, and University of Minnesota Duluth. This paper presents the institutional context, geotechnical engineering curricula, educational factors considered, results of statistical analyses, conclusions, and suggestions for future research. Based on the institutions in this study, this paper also provides a discussion of conditions for optimizing student learning in undergraduate geotechnical engineering courses.

Institutional Context and Course Formats

The six institutions participating in this study vary with regards to their size, type, location, and selectivity. Table 1 provides a comparison of the institutions using the current available 2016 data from the National Center for Education Statistics [17]. Four institutions are private and two are public; four are master's level institutions, one is a baccalaureate institution, and one is a doctoral research institution. University of Minnesota Duluth and Tufts had the largest enrollments; with regards to selectivity, Tufts and Bucknell had considerably lower acceptance rates than the other institutions in the study. Further details regarding the institutions and their geotechnical engineering curricula are provided in this section.

The Citadel enrolls approximately 2,100 students in its undergraduate Corps of Cadets (Day program) and approximately 700 undergraduate civilian students (Evening program). Out of these, approximately eight percent are female and 30% are minorities. As a requirement for graduation, Civil Engineering majors must take two geotechnical engineering courses in their senior year. The first course (Introduction to Geotechnical Engineering) 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 detached from the course, and 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, meeting three times per 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, 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.

Table 1. Institutional characteristics of the six institutions in this study.

Institution	The Citadel	Merrimack College	University of Evansville	Bucknell University	University of MinnesotaDuluth	Tufts University
Location	Charleston, S.C.	North Andover, Mass.	Evansville, Ind.	Lewisburg, Penn.	Duluth, Minn.	Medford, Mass.
Control	Public	Private	Private	Private	Public	Private
Carnegie Classification	Master's institutions: Larger programs	Master's institutions: Medium programs	Master's institutions: Small programs	Baccalaureate colleges: Arts & sciences focus	Master's institutions: Larger programs	Doctoral institutions: highest research activity
Undergraduate enrollment	2,773	3,443	2,248	3,571	9,967	5,508
Graduate enrollment	829	581	166	55	1,051	5,981
Acceptance rate	82%	82%	71%	30%	77%	14%

Merrimack College is an independent college in the Catholic tradition with undergraduate and master's programs in liberal arts, science, engineering, business, and education disciplines. In Civil Engineering, there are approximately 100 undergraduate and 20 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 depth elective in geotechnical engineering during their senior year (either Foundation Engineering, Earth Slopes and Retaining Structures, or Seismological and Geotechnical Aspects of Earthquakes). 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. Besides the class and lab, a 75-minute workshop is held once every other week that includes discussions of case studies and geotechnical engineering applications, as well as problem-solving sessions. Lecture and laboratory topics include soil composition and classification, compaction, groundwater, stress, settlement, and shear strength.

University of Evansville is a private institution affiliated with the United Methodist Church. 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 mainly focuses on subsurface investigations, analysis and design of foundations, slope stability, and design of retaining walls. The class meets three times a week for 50 minutes each. The students also take a one-credit-hour soil mechanics laboratory detached from the course.

Bucknell University is a private liberal arts university with an engineering program. Approximately 715 of 3,600 undergraduate students are enrolled in the engineering program, with about 32% being female students. Currently, 137 students are enrolled in the Civil and Environmental Engineering program (106 Civil and 31 Environmental). To complete the curriculum necessary for graduation, a student only has to complete and pass one geotechnical course, Geotechnical Engineering I (otherwise known as Soil Mechanics). Other geotechnical courses are offered as upper level (elective) courses; Geotechnical Engineering II (otherwise known as Foundation Engineering), Earthquake Engineering, Environmental Geotechnology, Ground Improvement, Advanced Soil Mechanics, Unsaturated Soil Mechanics, and Advanced Topics in Geotechnical Engineering. Foundation Engineering is offered every fall semester. The other electives are offered as feasible and generally at least two are offered every Spring semester. Soil Mechanics is scheduled as a 52-minute class session meeting three times a week, and a 2-hour laboratory session once a week. The laboratory portion of this course is offered with a W2 designation, which is a writing proficiency course that guides practice in writing and teaches the skills necessary to write for the discipline. The aim of this course is to explore soil behavior including both physical and engineering properties. This exploration is done by studying the fundamentals of soil mechanics (i.e., soil origin, mineralogy and structure, soil consistency and classification, phase relationships, compaction, permeability, seepage and seepage control, in-situ stresses and stress distribution, compressibility, and shear strength). At the end of the semester, some of the fundamentals are used in applications of lateral earth pressures and shallow foundations.

University of Minnesota Duluth is a regional comprehensive university with an enrollment of roughly 9500 students across 5 colleges. Approximately 3400 students and over one-third of the University's faculty are in the College of Science & Engineering. The Department of Civil

Engineering has 11 faculty, roughly 280 undergraduate students, and approximately 20 Master's students. Soil Mechanics is a required course in the junior year. The content focuses on the topics tested on the Fundamentals of Engineering Exam: engineering geology, soil properties and classification, stresses in soil, compaction, ground water flow, consolidation, soil shear strength (including determination of strength through laboratory and in-situ tests), and an introduction to application of strength in foundation design, slope stability, and lateral earth pressure. As a 4-credit semester long course taught twice a week, students attend two 75-minute lessons and one 110-minute lab weekly. The 11 labs in the course include specific gravity and minimum/maximum dry density, sieve analysis, hydrometer analysis, Atterberg limits, Proctor tests, sand cone tests, constant and falling head tests, using the finite difference method to draw flow nets, consolidation tests, direct shear tests, and unconsolidated-undrained (UU) triaxial tests. Soil Mechanics is offered in both the fall and spring semesters with multiple lab sections. Typically, class sizes are in the low 30's for classroom instruction and roughly 15, with students working in groups of two or three, for laboratory instruction. Geotechnical elective courses include Geotechnical Design, Advanced Soil Mechanics, Stability of Earth Masses, Rock Mechanics, Geotechnical Modeling, and Underground Excavation.

Tufts University has roughly 5500 undergraduates and 6000 graduate/professional students across its three campuses. Approximately 850 undergraduate students major in engineering, with Civil Engineering majors being around 10% of these students. The Department of Civil and Environmental Engineering has approximately 20 full-time faculty though only one-third are focused solely on civil engineering curriculum. All BSCE majors are required to take Introduction to Geotechnical Engineering, often in the fall of their junior year though some may take it in the fall of their senior year. The course meets twice a week for 75 minutes during the semester and has a weekly 150-minute laboratory. Course content includes soil index properties and classification, field exploration and in-situ testing techniques, hydraulic conductivity (1-D flow), compaction, stresses to soil masses under applied surface loading, 1-D consolidation and settlement, shear strength, and introduction to more advanced topics such as foundations, slope stability, seismic and earthquake loadings, lateral earth pressures, and contaminated site exploration and remediation. Weekly laboratories, taught by a separate instructor yet graded as if part of overall course, include test and analyses for grain size, specific gravity, Atterberg limits, hydraulic conductivity, consolidation, direct shear, and triaxial shear of soils. After taking the introductory course, students may take additional courses in geotechnical engineering that focus on design (Foundation Engineering or Earth Support Systems) or analysis (Groundwater and Field Methods in Geohydrology).

Comparisons of Course Curricula

Table 2 displays a cross-comparison of the contents of the introductory geotechnical engineering course at the six institutions used in this study. A few interesting trends are noted. The curricular units with the largest number of hours within most institutions' courses are soil composition and classification (including grain size distributions and index properties), settlement, and shear strength – all fundamental concepts in geotechnical engineering.

Table 2. Comparisons of the introductory geotechnical engineering course curricula at the six institutions.

Institution	The Citadel	Merrimack College	University of Evansville	Bucknell University	University of MinnesotaDuluth	Tufts University
Course title	Intro to Geotech. Engin.	Geotech. Engin.	Soil Mechanics and Soil Behavior	Geotech. Engin. I	Soil Mechanics	Intro to Geotech. Engin.
Curricular Topic:	*Class and laboratory hours devoted to each topic*					
Geology	3	3	2	1	1	1
Grain Size Distributions, Index Properties, Soil Classification	10	11	14	9	11	12
Phase Relationships	6	2	4	3	2	2
Compaction	6	5	7	5	7	5
1-D and 2-D Flow	9	6	8	10	9	4
Subsurface Stresses	6	6	6	8	5	4
Settlement	11	11	10	12	7	10
Shear Strength	11	14	6	9	10	10
Subsurface Investigations	3	0	1	2	4	3
Bearing Capacity	3	0	0	1	3	1
Foundations and Earth Retaining Structures	0	2	0	2	5	2
Case Studies	0	3	1	0	2	2

Groundwater flow (one- and two dimensional), subsurface stresses, and compaction also receive a significant number of class and laboratory hours. The topics of geology and phase relationships (which are generally narrower in scope in an introductory geotechnical engineering course) receive fewer hours at all institutions.

A larger deviation among the institutions, however, occurs among topics that bridge the first and second courses in geotechnical engineering: subsurface investigations, bearing capacity, foundations, earth retaining structures, and case studies. Subsurface investigation methods and field explorations comprised the curricula of five of the six institutions, to varying degrees (from 1-4 hours). At Merrimack, subsurface investigation methods are taught in the courses comprising the required senior-level electives in geotechnical design, and are excluded from the first course. Coverage of bearing capacity, foundations, and earth retaining structures also varied among the institutions; three institutions included both bearing capacity and foundations / earth retaining structures in their curricula, one institution (The Citadel) included only bearing capacity, one institution (Merrimack) included only a conceptual overview of foundations and earth retaining structures, and one institution (Evansville) included neither. The three institutions where bearing capacity, foundations, and earth retaining structures are covered in the introductory geotechnical course to a lesser degree share a common characteristic: a second geotechnical course is required (this perhaps reduces the pressure to include such material in the introductory geotechnical course). Finally, the institutions included varying amounts of case studies, ranging from 0 to 3 hours of course content. Not only was there variability in the number of hours devoted to case studies, but institutions varied in the manner in which case studies were incorporated into the course.

Educational Factors Considered

This study investigates seven educational factors that may correlate with the amount of knowledge gained in the conceptual understanding of geotechnical engineering topics. The educational factors include:

- Institution type (public vs. private)
- Class size
- Faculty rank (Assistant, Associate, or Full Professor)
- Class meeting time (morning class vs. afternoon/evening class)
- Laboratory format (attached to the course vs. separate from the course)
- Faculty obtainment of P.E. license (yes or no)
- Class length and format (three times a week for 50 minutes vs. twice a week for 75 minutes)

The smallest and largest class sizes in this study are 11 and 32, respectively. Four of the institutions have morning class times, and two have afternoon or evening classes. Three faculty are assistant professors, and three are associate professors. Three faculty have obtained P.E. licenses, and the others have not. Four of the institutions have laboratory attached to the course and two have laboratory detached from the course. In one of the institutions, the laboratory format is not only separate from the course, but it is also offered in a different semester.

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 (as presented in Table 3). It is important to note that only one of the questions (Q10) required a quantitative response, therefore emphasizing the testing for conceptual understanding of content. 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. Each instructor scored his or her own students against an established correct answer (with key words and phrases). Each question on the pre- and post-test was worth one point, although students had the opportunity to earn partial credit (e.g., 0.5 points) on questions.

Table 3. The short-answer questions on the pre- and post-test.

No.	Question
Q1	What are some of engineering characteristics of fine-grained soils?
Q2	What does high relative density and low void ratio indicate?
Q3	Why do we need to assess the shear strength of soil?
Q4	What is the difference between compaction and consolidation?
Q5	Why do we compact soils in earthwork?
Q6	Why is determination of water content of soil important?
Q7	What causes settlement in soils (i.e., sources of settlement in soils)?
Q8	What is the difference between normally consolidated and over-consolidated clay?
Q9	What is difference between the drained condition and undrained condition?
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.

Results and Discussion

Figure 1 illustrates the mean and standard deviation of overall scores on the pre- and post-test across the institutions for various educational factors in this study. The pre-test means range from 1.46 (laboratory separate from course) to 3.38 (private institutions) out of possible 10 points, and the pre-test standard deviations range from 1.0 to 1.78. The post-test means range from 6.54 (corresponding to late afternoon classes) to 7.24 (faculty with Associate professor rank), and the post-test standard deviations range from and 1.42 to 1.81. There is considerable dispersion among institutions and variables in terms of the pre-test scores (with a range of approximately 2 points, from a minimum of 1.46 to a maximum of 3.38), but surprisingly low variation among institutions and variables in terms of the post-test scores. In fact, all the mean post-test scores fall within an approximately 0.7-point range (from 6.54 to 7.24). For the institutions considered in this study, the data suggest that educational factors more heavily influence a student's preparation for geotechnical engineering (and exposure to prior geotechnical engineering concepts) rather than the student's understanding of these concepts after completing the course.

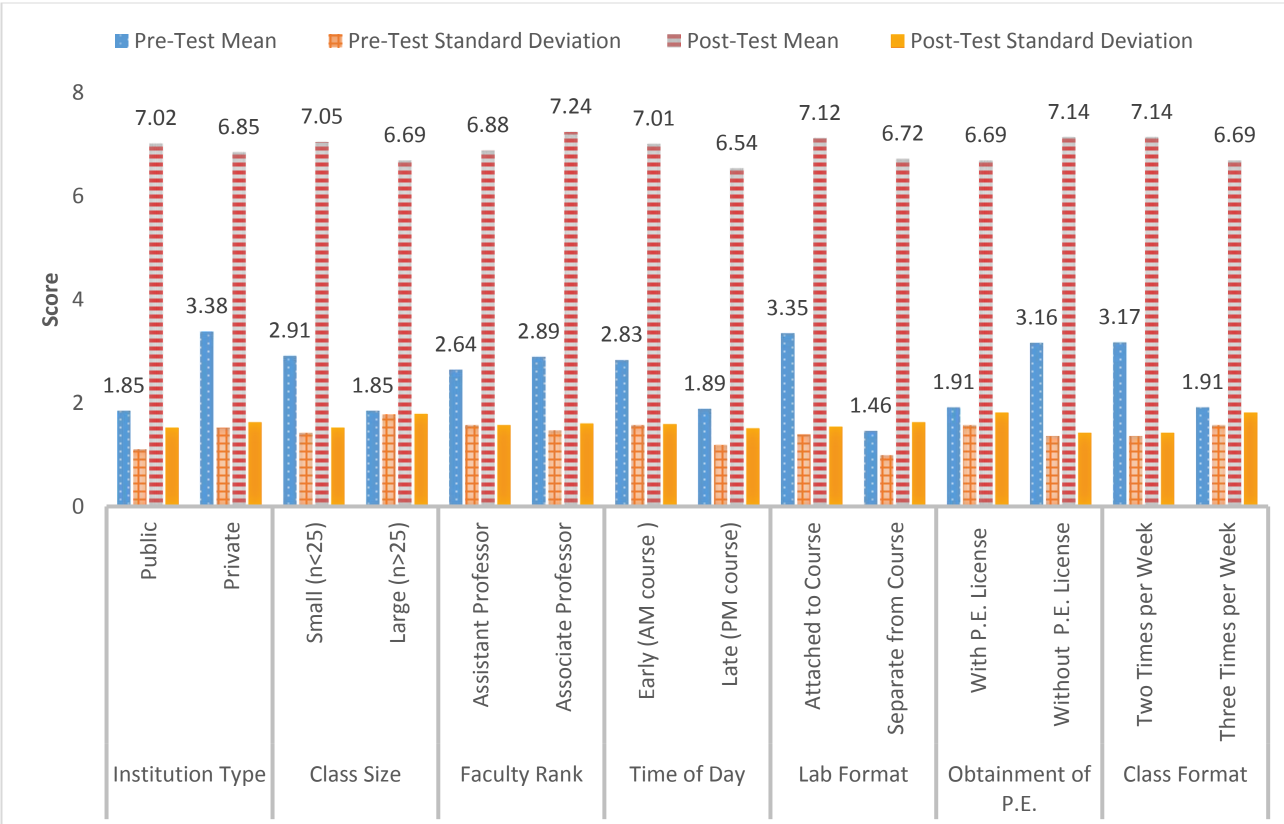

Figure 1. Mean and standard deviation of pre- and post-tests for various educational factors.

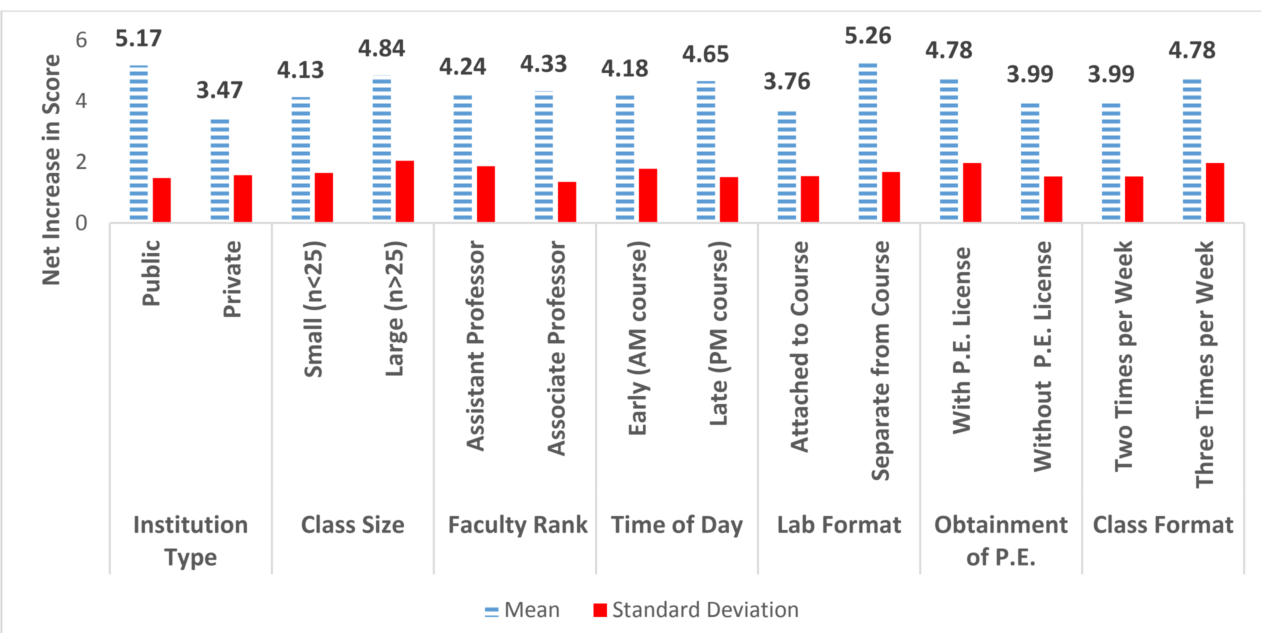

Figure 2. Mean and standard deviation net increase in scores from pre- to post-test.

Figure 2 displays the net increase in scores from pre- to post-test for the educational factors across the institutions in this study. Means and standard deviations of net increase in score from pre- to post-test range from 3.47 to 5.26 and 1.47 to 2.04, respectively. Figure 2 also illustrates that at all institutions, regardless of the educational factors considered, students experience significant gains in conceptual understanding of geotechnical engineering concepts during the course.

A Pearson Correlation statistical analysis was employed to determine which educational factors correlate to the net increase in score results. The statistical analysis revealed that two of the variables in this study have statistically significant influence on the amount of conceptual knowledge gained (i.e., net increase in score from pre- to post-test): the institution type and laboratory format. Table 4 presents the correlation coefficients for the seven mentioned variables. The strongest significant positive correlation (0.49) exists between the net increase in score and the institution type, with greater increases for public institutions. A significant positive correlation (0.43) exists between the net increase in score and the laboratory format, suggesting a greater increase at institutions with laboratories detached from classes. A possible explanation is the small sample size of institutions in this study.

Besides laboratory format and institution type, there is little to no correlation between the other variables and the net increase in score. A weak correlation exists between the following variables and the net increase: time of day (0.17), class format (-0.23), and faculty obtainment of P.E. license (0.23). These results are statistically significant at the 10% level. For time of day, the net increase was slightly higher for courses meeting in the afternoon than in the morning, perhaps indicating college students are often more engaged later in the day. Students enrolled in classes meeting three times per week displayed a slightly greater net increase than students enrolled in classes meeting twice a week, perhaps because they have additional days of contact with the material. Finally, the net increase was slightly higher in courses for faculty who have their P.E. license, suggesting that the instructor’s attainment of professional licensure indicates teaching that allows for students to better grasp the fundamental course concepts.

The results in Table 4 also show that there is no association between the class size or faculty rank and the amount of conceptual knowledge gained in the introductory geotechnical course across the institutions in this study. However, note that the maximum class size assessed in this study is 32 (which many institutions may consider small to medium); therefore, the data for class sizes from this study precludes deductions for the effect of larger class sizes in geotechnical engineering. Likewise, all the classes in this study were taught by either Assistant or Associate Professors; therefore, deductions based on other ranks (e.g., Full Professor, non-tenure-track positions, etc.) are precluded.

Table 4. Correlation coefficient, r, for seven educational factors and the net increase in score.

Variable	Pearson Correlation	P-value
Class size	0.06	0.176
Time of Day	0.17	0.06
Class Format	−0.23	0.09
Laboratory Format	0.43	< 0.001
Institution Type	0.49	< 0.001
Faculty Rank	0.02	0.402
Obtainment of PE	0.23	0.09

Conclusions:

Using data from six institutions, this study assessed several educational factors that may correlate with the amount of knowledge gained in the conceptual understanding of geotechnical engineering topics. The following conclusions can be made based on the results of the study:

- Among the variables analyzed, intuitional type and laboratory format emerged as dominant variables in the net gain in students' learning from the beginning to end of the semester. The net increase was significantly larger at public institutions and at institutions that have a separate course and laboratory (though this latter correlation requires more data).
- A weak correlation exists between the following variables and students' gains in conceptual understanding throughout the semester: class time, class format (2 vs. 3 times per week), and whether or not the faculty member has a P.E. license. Students in classes meeting in the afternoon (versus the morning), classes meeting three times per week (versus two times per week), and classes taught by faculty with professional licensure displayed slightly greater increases in their scores on this assessment instrument throughout the semester.
- Based on the sample of institutions in this study, no association exists between the class size or faculty rank and the amount of conceptual knowledge gained in introductory geotechnical course. However, most class sizes in the dataset were on the small to medium side, and the faculty members are all Assistant or Associate Professors.
- There is considerable dispersion among various educational factors in terms of the pre-test scores, but surprisingly low variation among institutions and variables in terms of the post-test scores. For the institutions considered in this study, the data suggest that some educational factors heavily influence a student's preparation for geotechnical engineering. However, regardless of the education factor, students' overall understanding of geotechnical engineering concepts after completing an introductory course increases significantly.

It is important to note that the results of this study are limited to the six institutions (with N = 232 student samples) assessed in this study and should not be generalized to draw broader statistical conclusions. Future research will focus on analyzing new data by student characteristics using similar methods as Ghanat et al. [1]. Additionally, research will consider instructor-focused factors including instructional methods (i.e. traditional vs. hybrid vs. flipped, percentage of lesson spent on active learning, slides vs. boards, etc.) and instructor training (i.e. on-campus workshops, off-campus workshops, etc.). It is expected that student learning will be strongly tied to faculty characteristics, classroom habits, and pedagogy, in addition to educational factors such as class/laboratory format and institutional characteristics. As more data are collected in the coming years, perhaps the results could help identify best practices for organizing civil engineering curricula to optimize gains in student knowledge throughout various courses.

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