Development of an Advanced Field and Laboratory Testing Course for Geotechnical Engineering Students

N. Derbidge & G. Fiegel

California Polytechnic State University, San Luis Obispo, USA
nderbidg@calpoly.edu, gfiegel@calpoly.edu

ABSTRACT: The paper describes the development of student learning outcomes, activities, and assignments for an advanced geotechnical engineering course focused on field and laboratory testing. The learning outcomes were developed using Bloom's Taxonomy. Some of these outcomes include: log a borehole and prepare final borehole logs; analyze relationships between stress history and shear strength for a local site; compare side-by-side SPT/CPT results; and evaluate the effects of sample disturbance on laboratory consolidation and strength test results. During the course, the authors work with local contractors, consultants, and students to excavate borings, perform in situ tests, and collect soil samples at a nearby site. Throughout the term, the students perform laboratory tests on collected soil samples and develop a site characterization report. In the paper, the authors discuss their experiences developing and implementing field and laboratory learning activities. The authors reflect on their experiences working together to develop and teach the course. Insight is offered on addressing logistics for laboratory-intensive courses and teaching advanced geotechnical concepts.

Keywords: field testing, site characterization, sampling, laboratory, learning outcomes

1 Introduction

The paper describes our experiences developing and teaching an advanced geotechnical engineering course on field and laboratory testing and site investigations. We provide details regarding format and structure of the course as well as the intended audience. In addition, we list and describe the course learning outcomes. These outcomes provided guidance for the authors during the preparation of lesson plans, laboratory activities, field activities homework assignments, formative assessments, and summative assessments. We have taught this course every year since 2016. The course is offered at the graduate level at California Polytechnic State University, San Luis Obispo (Cal Poly). However, enrolment typically includes an even mix of undergraduate and graduate students. The paper outlines the laboratory and field learning activities we developed, assessed, and improved over the past four years. Also described are course activities and assignments. We conclude the paper with discussions of lessons learned and strategies for implementing similar learning experiences at other institutions.

2 Background

2.1 Program, Enrolment, and Format

We teach the subject course for seniors and graduate students studying civil engineering and related disciplines. At Cal Poly, the academic year includes four quarters, each eleven weeks long. Course instruction takes place over a ten-week period. Instructors administer their final examinations during the eleventh week of the term. The subject course represents a 4-unit lecture-laboratory offering. Each week, the students meet with their instructor in the classroom (i.e., lecture) for two hours and in the laboratory for six hours. A typical course schedule will have the 2-hour lecture assigned Tuesday morning and the laboratory assigned as two 3-hour sessions on Tuesday and Thursday afternoons or as a single 6-hour session on Thursday afternoon. The subject course is an optional elective in the civil engineering program. Recent enrolments in the course have ranged between 15 and 20 students.

We divided the course into the primary subjects or "learning modules" listed in Table 1. We selected these topics based on an assessment of knowledge and skills needed for undergraduate and graduate students entering geotechnical engineering practice, particularly in California. We address the topics in the order presented in Table 1. Students learn about site investigations and the process of developing geotechnical recommendations from site reconnaissance to field testing to laboratory testing to report preparation. Within the laboratory portion of the course, we provide time for field drilling, sampling, cone penetration testing, and extensive laboratory testing. Drilling and cone penetration testing are performed on campus, in collaboration with local contractors. During a typical field investigation, we excavate two to three borings and complete one to three cone penetration soundings.

Preparation of the preliminary geotechnical engineering report represents the primary objective of our project-based learning approach to the course. Students in the course work together in groups of 3 or 4 persons to complete their assignments. Throughout the term, instruction and learning activities support the completion of the project. Additionally, we include supplemental activities designed to introduce advanced concepts in consolidation and shear strength theory. The supplemental activities also assist us in "training" the students to develop field and laboratory best practices.

Table 1. Primary Course Subjects or Learning Modules

Number	Learning Module	Approx. Course Fraction
1	Index Testing and Soil Classification Review	5%
2	Site Reconnaissance and Desk Studies	10%
3	Subsurface Investigations, Exploration, and Sampling	10%
4	In Situ Testing: Cone and Standard Penetration Tests	10%
5	Advanced Consolidation Testing and Concepts	15%
6	Advanced Shear Strength Testing and Concepts	20%
7	Stress History and Behavior of Clay Soils	10%
8	Undrained versus Drained Loading and Stress Paths	10%
9	Expansive Soil Behavior and Evaluation	10%

During the learning modules, we present terminology, definitions, concepts, theories, problem-solving techniques, testing procedures, design guidelines, and other information. We support student learning using in-class lessons, laboratory exercises, supplemental notes, technical articles, and textbook readings. The in-class lessons involve considerable work on the chalkboard (or white-board) and include frequent student questioning (Estes et al., 2004). The supplemental notes include learning outcomes, details on important concepts, problem solving tips, case histories, and examples prepared by the authors. The students download these notes for free from the course website. We assign research and technical articles to support the supplemental notes, in-class lessons, and laboratory work. We use freely available, state-of-the-practice industry design manuals as the primary course texts (e.g., Mayne et al., 2001; Robertson and Cabal, 2015; Sabatini et al., 2002; Samtani et al., 2006).

2.2 Prerequisites and Prior Learning

Graduate students may enroll in the subject course as long as they demonstrate previous learning related to geotechnical analysis and design. Undergraduates who wish to enroll need to complete a prerequisite junior-level course on introductory geotechnics and analysis. A laboratory that accompanies this course includes experiments on soil index testing, hydraulic conductivity, shear strength, and others. After completion of the introductory course, undergraduates must also complete a prerequisite senior-level analysis and design course on shallow foundations. Students in this course synthesize knowledge from previous courses and begin to develop their geotechnical design skills. The second course includes a learning module on settlement and intermediate concepts related to consolidation theory.

2.3 Learning Outcomes

Course learning outcomes define what the students should know and be able to do upon completion of a course topic (Donnelly and Fitzmaurice, 2005; Fiegel, 2013). We identified essential knowledge and skills for the learning modules listed in Table 1. We then developed matching learning outcomes. These learning outcomes are defined in the supplemental notes and on the course website. We reference these outcomes throughout the course to orient the students to important concepts.

Bloom’s original taxonomy of skills for the cognitive domain included six levels of understanding of a concept or topic, ranging from ‘knowledge’ at the lowest level to ‘evaluation’ at the highest level (Bloom et al., 1956). Anderson et al. (2001) revised Bloom’s taxonomy by proposing a framework with ‘Knowledge’ and ‘Cognitive Process’ dimensions. The latter dimension closely resembles the original taxonomy: it represents a continuum of increasing cognitive complexity with six categories (or levels) spanning lower-order to higher-order thinking skills. The revised taxonomy includes the following six levels: (1) remember; (2) understand; (3) apply; (4) analyze; (5) evaluate; and (6) create. The revised version of the taxonomy reflects advances in educational research since Bloom’s original work and provides a tool for instructors developing curricula and assessing performance.

We used the revised taxonomy when developing learning outcomes for the subject course. Table 2 shows an action verb for each outcome along with an estimated level of achievement in the cognitive domain. For a senior or graduate level engineering design course, we believe it is essential to identify several outcomes for achievement levels five and six (i.e., “evaluate” and “create”).

Table 2. Learning outcomes for the subject course

Action verb	Outcome*	Level
Classify…	soils during a drilling operation using visual-manual procedures	Analyze
Log…	a borehole and prepare final borehole logs	Apply
Collect and test…	soil samples for classification, strength, and compressibility	Apply
Compare and contrast…	test results with findings in peer-reviewed scholarly works	Evaluate
Interpret and compare…	the results of undrained triaxial shear tests	Analyze
Assess…	the swell potential of a soil	Evaluate
Develop…	a stress history profile for a soil site	Analyze
Develop…	relationships between stress history and shear strength for a soil site	Evaluate
Appraise…	the applicability of SPT and CPT empirical correlations for a soil site	Evaluate
Classify…	soil behavior type using CPT measurements	Analyze
Compare…	side-by-side SPT and CPT results	Analyze
Determine…	the effects of sample disturbance on laboratory test results	Evaluate
Prepare…	a preliminary Geotechnical Engineering Report for a soil site	Create

* - SPT = Standard Penetration Test; CPT = Cone Penetration Test.

2.4 Geotechnical Engineering Experience

Prior to designing and teaching the subject course, we collaborated in developing course content and activities for our program's introductory geotechnical engineering course and laboratory. As we developed and piloted different versions of the subject course, we undertook a multi-year plan to upgrade and modernize our laboratories. In support of this effort, we focused on purchasing equipment and implementing renovations that would provide opportunities for project-based undergraduate student learning and instruction as well as advanced research by faculty and graduate students.

We were confident that we could transform the subject course because of our previous collaboration together, our past success working with local engineering consultants and contractors, and our past professional experiences in academia and engineering practice. Teaching a course like this requires considerable time and effort, where an instructional team of faculty and/or graduate assistants is better prepared for success than a single individual. In addition, success while teaching in the field and laboratory requires the instructional team to have a broad understanding of geotechnical engineering concepts, design methods, field and laboratory testing procedures, instrumentation, and equipment.

We have considerable experience teaching and working in geotechnical practice, and specifically in laboratory and field-testing environments. Having taken a somewhat unique career path and journey, our lead author worked as a geotechnical consultant in California for over 15 years before transitioning to teaching and academia. His experience includes dozens of projects such as highway improvements and bridges, commercial developments, nearshore structures, slope reconstructions, and a variety of public works projects. He also served as construction services and laboratory manager. As laboratory manager, he was responsible for sophisticated and routine geotechnical testing services for numerous offices in California. In his current role, our lead author holds a dual appointment: (1) serving as an instructional support technician for our geotechnical, materials, structures, and pavement laboratories; and (2) teaching geotechnical and materials engineering courses. Forming an instructional team with broad technical and practical experience was essential for success in this course.

3 Course Activities and Assignments

3.1 Site Characteristics and Accessibility

We teach at an institution that supports a large agriculture and environmental sciences college. Therefore, available outdoor spaces (e.g., crops fields and rangelands) provide opportunities for field work and investigation. Several sites on campus are underlain by alluvial deposits consisting of fine- and coarse-grained sediments ranging in thickness from 5 to 25 meters. The fine-grained soils consist primarily of normally to slightly overconsolidated lean clays, while the coarse-grained soils are typically medium to coarse sands and gravels. These deposits are underlain by significantly weathered and relatively weak sedimentary bedrock (e.g., sandstone, claystone, siltstone). Groundwater at the sites fluctuates throughout the year, but is typically found within about 5 meters from the ground surface.

Available sites on campus provide an ideal environment for instruction, as they permit hollow-stem auger drilling, standard penetration testing, thin-walled tube sampling, cone penetration testing, and groundwater monitoring. Open spaces in the vicinity of an exploration location allow us to create field "classrooms" with tables and dispersed student work stations (see Figure 1). In addition, the sites are easily accessible - students typically walk or ride their bikes to the sites - and relatively free of utilities. Importantly, we coordinate our field efforts with utility locating services; however, the learning exercise is commonly trivial and uninteresting since work takes place primarily in undeveloped agricultural fields.

Figure 1. Field drilling and instruction on borehole logging

Overall, the success of the subject course depends, to a certain extent, on free and repeated access to these field experiment sites. Although uncertainty is expected during any geotechnical investigation, our continued work with these campus sites has limited some of the variables associated with field work and allowed us to focus on teaching and instructional design.

3.2 Benchmark Homework Assignments

As noted, students work in teams to produce a preliminary geotechnical engineering report. The report is due at the end of the ten-week course. During the first week of instruction, we provide the students with a geotechnical report outline that is consistent with the format used by consultants in practice. To help students meet the due date for the report, we assign benchmark homework assignments. These assignments address important sections of the report and elements of the report preparation process.

We distribute the deadlines for the benchmark assignments throughout the term. Eventually, the students merge their completed assignments into a final report, often with little modification. Table 3 provides the approximate schedule and brief descriptions of the benchmark homework assignments.

Table 3. Benchmark homework assignments

Week*	Assignment	Description
1	Desk Study and Site Visit	Review geotechnical reports and geologic maps for a nearby soil site. Prepare a preliminary soil profile, field exploration plan, and site description.
2	Summarize Applicable Test Methods	Review all ASTM test methods used during the course (about 12 methods). Summarize each method in a brief paragraph; include proper citations.
4	Determine Seismic Site Class	Using results of the field exploration, determine the seismic site classification according to the local building code. Submit calculations and a paragraph describing the procedure and all assumptions.
5	Digitize Boring Logs and Develop Soil Profile	Use a spreadsheet template (provided) to digitize site boring logs. Use boring logs, CPT soundings, and visual-manual soil classifications to create a field exploration plan and final subsurface soil profile.
8	Stress History and Consolidation Parameters	Prepare a table summarizing the results of consolidation tests (e.g., OCR, c_v, C_c, C_r, sample quality, etc.). Prepare a figure of OCR vs. depth. Provide a brief written reflection on the stress history for the site. Include sample calculations and graphical constructions.
9	Interpret Swell Data	Prepare a table summarizing results of all swell tests (i.e., expansion index, swell pressure, dry unit weight, initial saturation, Atterberg limits, etc.). Compare the test results to published values. Provide a brief written reflection on earthwork and grading recommendations for the site.

* - The subject course is taught over a 10-week term.

We modify the objectives for development and improvement of the site with each course offering. For example, students may be asked to plan their geotechnical investigation to support the design and construction of: (1) a warehouse, where shallow foundations are appropriate; (2) a parking structure, where deep foundations and retaining walls are appropriate; or (3) a manufacturing facility, where tolerable settlements are strictly low. Given the time constraints of the quarter and resources available, we cannot conduct a comprehensive site investigation for these projects; only a select number of field explorations are possible. However, defining a project objective provides the students with valuable context regarding the benchmark homework assignments. Students use project information when deciding on exploration recommendations and when analyzing field and laboratory test results.

3.3 Laboratory Testing Schedule and Assignments

We work with the students to design a term-long laboratory testing schedule. The students follow this schedule in generating their own test data and results. These data and results are then incorporated into interpretation assignments, which the students complete as individuals and in laboratory groups. An initial set of laboratory tests are assigned to help the students familiarize themselves with standards and best practices. A final set of laboratory tests are conducted on samples collected during field exploration. The students incorporate the results of these latter tests into their geotechnical engineering report. An outline of a typical laboratory testing schedule is included in Table 4.

For the initial assignments, students perform tests on pottery clay. Performing consolidation and shear tests on this material teaches students how to properly and efficiently perform different test methods. The stakes are lower at this time, before the students test field samples. The following characteristics make pottery clay an ideal introductory testing material: uniformity, homogeneity, readily available, fairly inexpensive, non-sensitive, nearly saturated, and forgiving during test specimen preparation (i.e., handling, carving, trimming, etc.). We purchase the clay in approximately 200- to 300-millimeter blocks from the craft center on campus. The initial consistency is generally "soft" to "medium stiff."

While preparing the pottery clay specimens, the instructor explains and demonstrates mistakes. More common testing errors include poor trimming technique (that leaves a gap between the specimen and the ring wall), disturbing the specimen due to improper handling and/or trimming, not aligning porous stones and end caps, neglecting to measure and/or record important specimen information, not trimming the ends of the specimen perpendicular to the loading axis, not leaving enough capacity in a dial indicator to capture the change in height during an entire test, and neglecting to confirm that instrumentation and/or equipment are in proper working order.

Table 4. Typical laboratory testing schedule

Week*	Assignment	Material Tested	Comments
1	Incremental and Constant Strain Rate Consolidation Testing	Pottery Clay	Begin with long-term tests; use data for supplemental interpretation assignments; train students for eventually working with site samples.
2	Consolidated Undrained Triaxial Shear Testing	Pottery Clay	Teach students to prepare, mount, saturate, and test triaxial specimens.
3,4	Drilling and Sampling	In Situ Soils and Rock	Perform cone penetration tests (CPTs); perform standard penetration tests (SPTs); gather disturbed and undisturbed samples.
5	Prepare laboratory test assignments	----	Confirm sample suitability; assign laboratory tests; prepare a cost estimate of laboratory testing.
6,7,8	Perform Laboratory Tests for Geotechnical Report	Collected Site Samples	Test samples gathered during drilling; students work together to perform the laboratory work small groups.
9	Swell Testing	Collected Site Samples	Perform a variety of swell tests as a class.
10	Report Preparation	----	Complete all laboratory reports and share results.

* - The subject course is taught over a 10-week term.

As a class, students perform six incremental consolidation tests on pottery clay, including pairs of tests at different load increment ratios (LIRs). Students use data collected during the consolidation tests to review different methods for interpreting consolidation test results, evaluate the similarity of results between companion samples, comment on the influence of varying the LIR, and compare coefficient of consolidation (c_v) at different load increments and with different interpretation methods. Students write a brief report addressing whether or not the test results support the conclusions from research papers on relevant subjects (Amundsen et al., 2016; Paniahua et al., 2016; Vipulanandan et al., 2009) and information provided in Holtz et al., (2011). We encourage students to consult this textbook during the subject course. The text is required in prerequisite geotechnical courses.

We use an estimate of the clay's preconsolidation stress from the consolidation tests for interpretation of Stress History and Normalized Soil Engineering Parameters (SHANSEP) during subsequent triaxial shear testing (Ladd and Foote, 1974). In teams of three, students trim and mount four pottery clay specimens for consolidated undrained (CU) triaxial tests with pore-pressure measurements (ASTM, 2011). We consolidate the specimens to known overconsolidation ratios (OCRs) and follow a modified SHANSEP evaluation procedure. We incorporate the results of the CU triaxial tests into a homework assignment on stress paths and interpretation of triaxial data. Students also calculate Skempton's "B" and "A_f" parameters and compare results with published values (Skempton, 1954).

After completing the laboratory pottery clay tests, students perform a field exploration. As noted in Table 4, this exploration occurs over a two-week period. Drilling typically involves hollow-stem auger drilling. We collect soil samples using the standard penetration test (SPT), a Modified California driven split-spoon sampler, and a thin-walled (Shelby) tube sampler. We perform cone penetration tests (CPTs) with pore-water pressure measurements in the vicinity of previously excavated boreholes. We typically perform pore pressure dissipation tests during CPT soundings. Time permitting, we may conduct seismic testing during one of the CPT soundings to measure shear wave velocities for the site soils. The results of the seismic tests help inform the seismic site classification assignment described in Table 3. This table summarizes additional benchmark assignments associated with the field exploration work.

Following field exploration, the students test the disturbed and undisturbed samples that they retrieved and logged (see Figure 2). Table 4 provides the approximate laboratory testing schedule for the latter half of the term. During the fifth week, the students review the condition of the collected samples and prepare a laboratory testing schedule. Testing proceeds during the next three weeks. The bulk of the subsequent laboratory work includes index testing (i.e., Atterberg limits and soil classification), incremental consolidation testing, and triaxial shear testing (i.e., CU and UU). During this time, the instructor will typically perform constant strain rate (CSR) consolidation tests to demonstrate the test method and supplement the student work with additional consolidation test results. Additional benchmark homework assignments associated with this laboratory testing are summarized in Table 3.

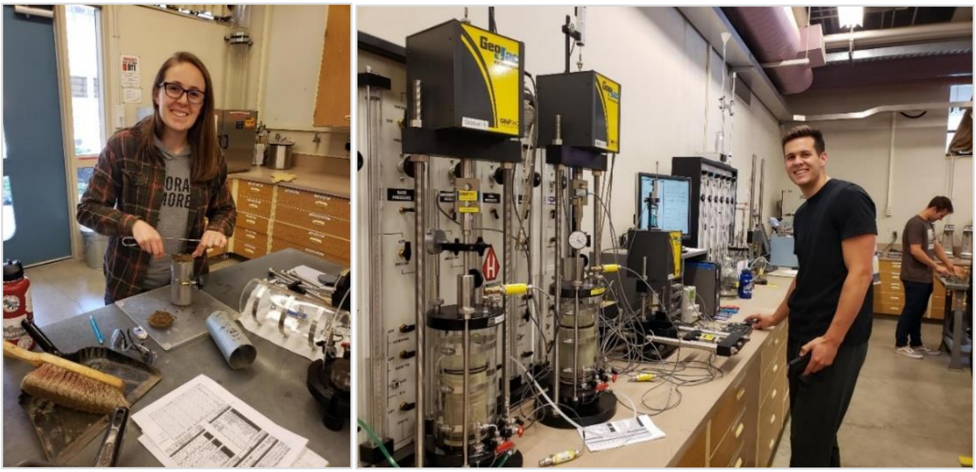

Figure 2. Students in the laboratory testing collected soil samples

As indicated in Table 4, we perform swell tests during week nine. During the lecture portion of the course, we discuss methods to evaluate expansive soil, heave prediction, and mitigation measures. In the laboratory and as a class, we perform an expansion index (EI) test (ASTM, 2019) along with several different methods to evaluate one-dimensional swell pressure (ASTM, 2014). We use our consolidometers and front loading oedometer frames to conduct the latter tests. Students analyze the swell test results as part of a benchmark homework assignment that they later merge into the geotechnical engineering report (see Table 3).

4 Lessons Learned

4.1 Dealing with Mistakes

Mistakes are naturally part of the learning process - they often present a "teachable moment" for the instructor. At times, we have struggled to find a balance between learning from mistakes, providing teachable moments, and generating quality and analyzable data from inexperienced testers. Ultimately, students are tasked with defining a soil profile and selecting characteristic soil parameters for each layer to use in their analyses. Varied data are available including CPT soundings, SPT blow counts, hand torvane and pocket penetrometer results, laboratory mini-vane results, over a dozen triaxial tests results (typical), at least half a dozen consolidation results (typical), dozens of moisture and density results, and at least a dozen classification test results. As a class, we ask the students to collect many soil samples, perform a high number of laboratory tests, and share test results among their project groups. These strategies help us in addressing mistakes. Back-up samples are available for testing and provide opportunities for the students to examine (and re-examine) uncertainties and errors during testing. Sharing results among groups provides increased motivation for the students to be efficient and careful in their testing, as they quickly understand that others are depending on their test results and quality outcomes. Others have commented on the value associated with learning by doing and asking students to share responsibility in their own learning (e.g., Blum, 2016). Being intentional with instructional design in these areas can increase intrinsic motivation and improve student learning.

Additionally, we teach the students to assess consistency among the test data and results when selecting characteristic soil properties for inclusion in their geotechnical reports. For example, an apparently anomalous test result can be compared with CPT data, SPT blow count data, other laboratory results, and published values. Having collected considerable laboratory and field test data affords us this opportunity. As a class, we examine anomalies and discuss likely reasons for misleading results. Identified mistakes often result because of inexperience and provide opportunities to discuss testing errors that may also occur in practice. Typically observed testing errors include: misalignment of porous stones during consolidation testing, forgetting to unlock the loading piston during triaxial testing, improper and/or rough handling of a sample leading to disturbance, incorrect soil classification leading to improper test selection, incorrect sample labels, incorrect calculation and/or assignment of confining loads and stresses, and others. An important intended outcome of the laboratory testing is for students to begin to develop a critical eye when evaluating and relying on test results. Some examples follow.

Our test site consists primarily of clayey soil with some sand layers over bedrock. When performing a SPT within a hollow-stem auger below the groundwater table in a sandy layer, the potential exists for sand to flow into the auger after the center bit is removed and before the sampler is placed back down the hole. In this case, the bottom of the hole is destabilized and disturbed as sand may flow a meter or more into the lead auger. When the SPT sampler is lowered into the auger, it bottoms on the disturbed sand instead of undisturbed soil. "Flowing sand" may be assumed to occupy the bottom of the borehole when the top end of the center rod sticks up above the top end of the augers more than the length of the sampler. Mistaking blow counts in "flowing sand" as accurate could result in an extreme mischaracterization of soil consistency. We use CPT soundings adjacent to borings to illustrate the hazard of not recognizing potentially erroneous blow counts. In one case, at a depth of 9 meters below the ground surface, we observed signs of "flowing sand" prior to performing an SPT. Students noted the potential for erroneous blow counts on their field logs. We subsequently asked students to create a graph of corrected blow count versus depth using SPT and CPT data. The corrected blow count for this test was 25. Data from an adjacent CPT suggested a corrected blow count of 4 for the same depth.

Additionally, various errors may occur when preparing specimens for consolidation testing. Preparation errors are revealed in the data. Figure 3 shows results of four consolidation tests performed at different LIRs on specimens trimmed from the same block of pottery clay. The resulting consolidation curves are consistent, with the exception of Specimen D. This specimen was trimmed slowly and dried slightly before testing. Also, the students used dry filter paper to protect the porous stones - moist paper was used for the other specimens. The initial saturation of Specimen D was 90 percent. Initial saturation levels for the other specimens ranged from 95 to 97 percent. Each specimen was inundated with water after a seating load was applied and then loaded incrementally. As a class, we discussed and identified the preparation mistakes that likely produced the anomalous consolidation curve.

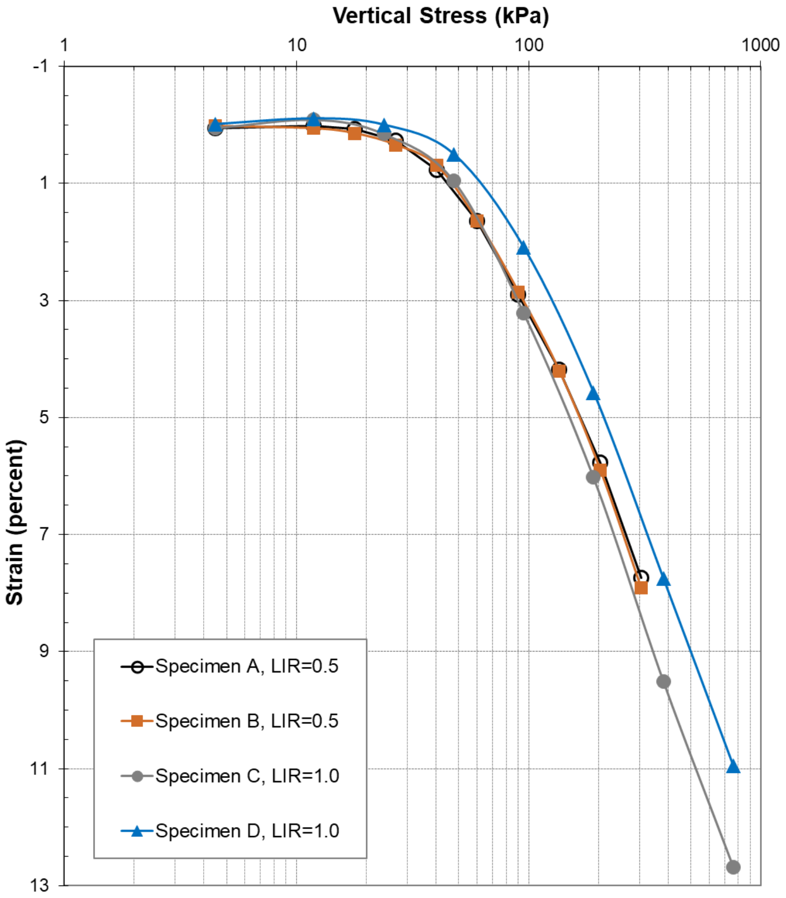

Figure 3. Anomalous results from incremental consolidation tests

4.2 Involving Everyone during Kinesthetic Activities

Typically, most students readily volunteer for hands-on work in the lab and field. However, some students prefer to observe. When students perform kinesthetic learning activities in the laboratory and field they tend to benefit in different ways from the traditional lecture format. Tranquillo (2008) suggests that kinesthetic activities offer the following benefits: (1) produces experiences that enable students to become more invested in the course; (2) allows time for students to make personal interpretations of concepts and connections to other ideas and concepts; (3) provide numerous opportunities for the instructor to check for understanding; and (4) allows instructors to create a rapport with students.

We use several different strategies to encourage all students to participate during the hands-on activities, which include the field exploration and laboratory testing programs. For example, during field exploration, we rotate between groups when processing collected samples. In addition, each student is responsible for creating their own boring log, even though they work in small groups to accomplish the day's tasks. This combination of individual and group responsibility encourages (and requires) open communication as the students share sampling information, drilling observations, and SPT blow counts. After creating the laboratory testing program and schedule, we assign each group a portion of the tests. Each group is given a variety of different tests to perform. To adhere to the compressed schedule and serve a relatively small group, each student needs to participate during all of the hands-on activities.

4.3 Sharing Data Efficiently

Students are charged with compiling all of the test results from testing performed by the entire class for the geotechnical report. Recording and reducing laboratory data consistently and efficiently has been a significant challenge for this course. Laboratory testing sessions are often busy with activity, as students work on a variety of tasks. In the past, we have struggled to have students consistently record all of the required measurements. To help with this challenge, we created spreadsheet-based laboratory worksheets for each of the tests performed. Most of the spreadsheets incorporate embedded figures or graphics to assist the reader in visualizing test results. For index and classification tests, students input their data into the spreadsheet worksheet and e-mail the file to the instructor. After quality assurance checks, the instructor uploads the results to the course website to allow access by all students. The instructor collects and reduces data for tests that require computer data acquisition (incremental consolidation with time rate data, triaxial compression, etc.). Processed results are uploaded as spreadsheet reports to the course website. This routine is consistent with geotechnical engineering practice: a laboratory performs tests and provides reports to the engineer. This process helps ensure the reports are accurate and consistent. Instead of reducing all data and producing reports, which can lead to delays and mistakes, students are free to invest most of their time interpreting and selecting characteristic soil properties. During a course like this, we are careful to not overwhelm the students with more information than they can handle (Kaufman and Schipper, 2018). In addition, we can use the open, accessible, and properly formatted worksheets to address learning outcomes related to data presentation and organization, spreadsheet design and programming, and visual communication.

4.4 Testing Resources

Having enough laboratory resources is another challenge for this class. The bottleneck for equipment access typically occurs with the triaxial cells and consolidation machines. We typically have four teams of students performing a variety of laboratory tests. With six consolidation machines we are able to generate enough data within the compressed testing schedule. We have six triaxial cells for the students to share during shear strength testing, which is adequate. Usually, the students will perform two CU triaxial tests, which commonly take almost two weeks to complete. Each group then has access to one triaxial cell to perform unconsolidated undrained (UU) triaxial tests. We have three load frames available for triaxial testing. The load frame packages we selected are computer-controlled with automatic data acquisition. The software package is flexible enough to perform non-routine research testing but is also intuitive for student use. During testing, the software provides a realistic visual schematic of the test setup with live readings for all sensors. We can use the software to generate real-time plots of data in seconds. We train students to operate the load frames and software during one laboratory testing session. Although we operated and maintained our own field drilling and testing equipment in the past, we now collaborate with local geotechnical contractors who complete the field exploration work in kind. The time and effort we have devoted to developing these partnerships has been well spent.

4.5 Assessment Efforts

We incorporate formative and summative assessment efforts during the course. Our formative efforts involve observation and mentoring of the students during testing as well as review of the benchmark assignments. We use these assignments to monitor student progress, provide positive feedback, offer guidance on errors and mistakes, and identify gaps in knowledge and understanding. If learning gaps are identified, we have time to schedule supplemental discussions and/or lessons prior to submission of final project reports. Summative assessment efforts involve primarily student evaluations of teaching and final report evaluations. Recent student evaluations have been overwhelmingly positive, which is expected to a certain extent, given the regular improvements and refinements made to the course over time, the small class size, the opportunities for one-on-one instruction, and the hands-on nature of the learning experience. In addition, the final reports have been consistently well written, organized, and presented. We use a scoring rubric when evaluating the final reports. We present the rubric to the students at the beginning of the term and intentionally link the rubric with key aspects of the geotechnical engineering report. Essential elements of the scoring rubric are outlined in Table 5.

Table 5. Geotechnical Engineering Report Scoring Rubric

Scoring Element	Percentage	Comments
Material Property Evaluation	25	Interpretation of field and laboratory test results, supporting analyses, presentation of results
Conclusions and Recommendations	30	Written summary of findings, foundation type selection and recommendations, construction considerations, supporting calculations
Site Conditions	20	Technical descriptions of work performed and findings, subsurface cross-section(s), field and laboratory data appendices
Presentation and Organization	5	Creation of a portfolio quality document
Clarity of Writing and Documentation	20	Tables, figures, technical writing, sources cited, reference section

5 Conclusions

In this paper we discussed the development and implementation of a project-based geotechnical field and laboratory testing course. Based on our success, we encourage other educators to consider similar learning outcomes and project-based learning activities in their own courses. We are happy to share our course materials and additional project details directly with others.

Through our experiences teaching and assessing this course, we have learned a lot about our students. These students often experience challenges when working in groups; need to improve their information literacy skills; require regular and constructive feedback; find the subject of geotechnical engineering interesting, relevant, and challenging; relate well to the subject matter when it is linked with contemporary and/or practice-oriented issues; require support and direction when asked to self-direct their learning; and appreciate hands-on demonstrations and project-based learning. Additionally, interaction with our students during field and laboratory activities (e.g., listening to their comments, observing their actions, addressing their questions, etc.) provides opportunities for knowledge checks that lecture formats do not easily accommodate. We reflected on these observations and a number of "lessons learned" as we revised and improved the course curriculum.

Acknowledgements

We appreciate the curiosity, hard work, and enthusiasm displayed by students in our courses. We thank the Civil Engineering Program at Cal Poly for their continued support. We appreciate the in-kind exploration and testing services provided by local geotechnical contractors Earth Systems and Gregg Drilling, who assist with field drilling and cone penetration testing, respectively. Staff from these organizations are always eager to provide unique learning opportunities for our students.

References

ASTM - American Society for Testing and Materials (2011). Standard Test Method for Consolidated Undrained Triaxial Compression Test for Cohesive Soils. D 4767-11, West Conshohocken, Pennsylvania, USA.

ASTM - American Society for Testing and Materials (2014). Standard Test Methods for One-Dimensional Swell or Collapse of Soils. D 4546-14, West Conshohocken, Pennsylvania, USA.

ASTM - American Society for Testing and Materials (2019). Standard Test Method for Expansion Index of Soils. D 4829-19, West Conshohocken, Pennsylvania, USA.

Amundsen, H.A., Thakur, V., Emdal, A. (2016). Sample Disturbance in Block Samples and Low Plastic Soft Clays. Proceedings of the 17th Nordic Geotechnical Meeting, pp. 159-168, NGM, Reykjavik, Iceland.

Anderson, L.W., Krathwohl, D.R., Airasian, P.W., Cruikshank, K.A., Mayer, R.E., Pintrich, P.R., Raths, J., Wittrock, M.C. (2001). A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives, Longman, New York, USA.

Bloom, B.S., Engelhart, M.D., Furst, E.J., Hill, W., Krathwohl, R. (1956). Taxonomy of Educational Objectives, Volume I: The Cognitive Domain, McKay, New York, USA.

Blum, S.D. (2016). I Love Learning; I Hate School, Cornell University Press, Ithaca, New York, USA.

Donnelly, R., Fitzmaurice, M. (2005). Designing Modules for Learning. In: O'Neill, G., Moore, S., and McMullin, B. (Eds.), Emerging Issues in the Practice of University Learning and Teaching. All Ireland Society for Higher Education (AISHE), Dublin, Ireland.

Estes, A.C., Welch, R.W., Ressler, S.J. (2004). Questioning: Bringing your Students along on the Journey. Journal of Professional Issues in Engineering Education and Practice, ASCE, 130(4), pp. 237-242.

Fiegel, G.L. (2013). Incorporating Learning Outcomes into an Introductory Geotechnical Engineering Course. European Journal of Engineering Education, Taylor & Francis, 38(3), pp. 238-253.

Holtz, R.D., Kovacs, W.D., Sheahan, T.C. (2011). An Introduction to Geotechnical Engineering, 2nd Edition, Pearson Education, Inc., Upper Saddle River, New Jersey, USA.

Kaufman, P., Schipper, J. (2018). Teaching with Compassion – An Educator's Oath to Teach from the Heart, Rowman and Littlefield, Lanham, Maryland, USA.

Ladd, C.C., Foote, R. (1974). A New Design Procedure for Stability of Soft Clays. Journal of the Geotechnical Engineering Division. ASCE, Vol. 100, No. GT7, pp. 763-786.

Mayne, P.W., Christopher, B.R., DeJong, J. (2001). Manual on Subsurface Investigations, Federal Highway Administration, Publication No. FHWA-NHI-01-031, Washington, D.C., USA.

Paniahua, P., L'Heureux, J.S., Lunne, T.L. (2016). Practice for Preconsolidation Stress Evaluation from Oedometer Tests. Proceedings of the 17th Nordic Geotechnical Meeting, pp. 547-556, NGM, Reykjavik, Iceland.

Robertson, P.K., Cabal, K.L. (2016). Cone Penetration Testing for Geotechnical Engineering, 6th Edition, Gregg Drilling & Testing, Inc., Signal Hill, California, USA.

Sabatini, P.J., Bachus, R.C., Mayne, P.W., Schneider, J.A., Zettler, T.E. (2002). Evaluation of Soil and Rock Properties, FHWA Geotechnical Engineering Circular #5, Report No. FHWA-IF-02-034, Washington D.C., USA.

Samtani, N.C., Nowatzki, E.A. (2006). Soils and Foundations Reference Manual, Volumes I and II, Federal Highway Administration, Publication No. FHWA NHI-06-088, Washington, D.C., USA.

Skempton, A.W. (1954). The Pore-Pressure Coefficients A and B, Geotechnique, Vol. III, No. 1, pp. 30-53.

Tranquillo, J. (2008). Kinesthetic Learning in the Classroom. Proceedings of the American Society for Engineering Education (ASEE) Annual Conference & Exposition, Paper AC 2008-599, ASEE, Pittsburgh, Pennsylvania, USA.

Vipulanandan, C., Bilgin, O.Y., Guezo, J.A., Vembu, K., Erten, M.B. (2009). Prediction of Embankment Settlement Over Soft Soils, Federal Highway Administration and Texas Department of Transportation, Report No. FHWA/TX-09/0-5530-1, Springfield, Virginia, USA.

Authors' bios

Nephi Derbidge, California Polytechnic State University (Cal Poly), USA

Nephi Derbidge is a Lecturer and Instructional Support Technician at Cal Poly, San Luis Obispo. He worked as a geotechnical engineering consultant in California for over 15 years before transitioning to teaching and academia. He earned a degree in Civil Engineering in 1997 and a California Teaching Credential (Mathematics) in 2003. Nephi has extensive geotechnical engineering project experience related to highway improvements and bridges, commercial developments, nearshore structures, slope reconstructions, and public works facilities. In addition, he has served as construction services and laboratory manager. As laboratory manager, he was responsible for sophisticated and routine geotechnical testing services for numerous geotechnical offices in California. In his current role, Nephi holds a dual appointment: (1) serving as an instructional support technician for Cal Poly's geotechnical, materials, structures, and pavement laboratories; and (2) teaching geotechnical and materials engineering courses.

Gregg Fiegel, California Polytechnic State University (Cal Poly), USA

Gregg Fiegel is a Professor of Civil Engineering and serves as Director of the University Honors Program. He began work at Cal Poly in 1995 after earning Ph.D. and M.S. degrees from the University of California, Davis. He is a Cal Poly alumnus as well as a registered Professional Engineer (P.E.) and Geotechnical Engineer (G.E.) in California. As an instructor in Civil Engineering, Gregg has taught numerous undergraduate and graduate geotechnical engineering courses. In addition, he co-led the initial design and implementation of the yearlong Civil Engineering Senior Design course. Gregg has extensive experience advising and teaching first-year students in Civil Engineering and Honors. The latter is an interdisciplinary program serving over 450 students from all 6 of Cal Poly's colleges and nearly 60 different majors. In Honors, he developed and now co-teaches a three-quarter, first-year experience focused on sustainability, environmental justice, project-based learning, leadership, and service.