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Problem-Based Learning with EFFECTs: Part II – Ground Improvement Module for Lab Courses – SFGE 2016

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SUMMARY: This paper describes the development and implementation of a problem-based learning (PBL) module in an undergraduate geotechnical engineering lab course. The PBL module is constructed within the Environments for Fostering Effective Critical Thinking (EFFECTs) pedagogical framework, which integrates active learning, collaborative learning, and reflection. The problem focuses on cement stabilization of soil in an unpaved road, and it is intended to introduce students to the concept of ground improvement. The PBL approach is a new enhancement to this lab course, and it was observed to create more student interest and engagement as compared to the traditional format.

KEYWORDS: active learning, cement stabilization, critical thinking, ground improvement, problem-based learning, shear strength

1 INTRODUCTION

Experimentation and hands-on learning are considered to be essential aspects of an undergraduate engineering education. To that end, lab courses have a significant role in the engineering curriculum. Instructional labs for some engineering disciplines concentrate on student learning of standard test methods. This is common in geotechnical engineering, where physical and mechanical properties of soils are determined using standardized experimental procedures, such as those recommended by the American Society for Testing and Materials (ASTM).

Teaching students these standard methods facilitates hands-on participation, but it does not inherently stimulate minds-on student engagement. In other words, the routine performance of experimental steps does not promote higher order thinking. There are a number of approaches that have been reported to address this challenge in geotechnical education. Dewoolkar et al. (2009) describe hands-on, inquiry-based educational modules developed as part of a larger curriculum reform effort. The application and significance of geotechnical lab tests can be connected using methods like case-based instruction (Phillips, 2008) and project-based learning (Kitch and Coduto, 2010; Anderson et al., 1985). Fiegel and DeNatale (2000) discuss a hands-on approach to integrate field-testing with lab tests to improve student understanding of soil properties.

This paper describes an approach for the development, implementation, and assessment of instructional materials using problem-based learning (PBL) in a geotechnical engineering lab course. The proposed approach utilizes the Environments for Fostering Effective Critical Thinking (EFFECTs) pedagogical framework (Pierce, 2016; Pierce et al., 2013). In this framework, students are presented with a realistic engineering problem that prompts a driving question. Using a decision worksheet, students prepare an initial estimate to the driving question based on their current state of knowledge. The decision worksheet captures two critical pieces of student thinking: the visual interpretation and understanding of the problem; and the estimation process using assumptions, approximations, and dimensional analysis. Once completed, the decision worksheet serves as a reference document for students to reflect upon as new knowledge is acquired through a series of active learning exercises. The PBL sequence ends with a final solution to the driving question, which is often presented in the form of a report.

The EFFECTs framework, as described above, can be adapted for success in all face-to-face instructional environments, but it is particularly suited for lab courses. At the University of South Carolina, the undergraduate geotechnical engineering lab course is structured using a traditional format, where students conduct standard lab tests for determining soil properties. The PBL sequence is a new addition to this lab course, and as such, it will be evaluated in terms of student interest, engagement, and learning compared to the traditional format.

2 EFFECT MODULE DESCRIPTION

An EFFECT module on ground improvement was created using the developmental flowchart described in a companion paper (Pierce, 2016). Its development was part of a program initiative for doctoral students to integrate teaching with their research. The doctoral student assigned to instruct the lab course is researching unpaved road stabilization with different admixtures, including cement. It was decided to construct a module that focuses on cement treatment of a plastic soil, in an effort to enhance student learning of soil shear strength. At the same time, this module is also used as a means for introducing students to ground improvement methods.

PBL within this framework concentrates on student learning of critical concepts within a relevant and meaningful context. Five core concepts in geotechnical engineering are incorporated into the module: phase diagrams, Atterberg Limits, compaction, unconfined compression, and shear strength using Mohr-Coulomb failure criteria. The PBL sequence was designed with the following activities: (1) completion of individual decision worksheets; (2) completion of group decision worksheets to achieve a consensus estimate of how much cement should be added to the soil; (3) performance of unconfined compression (UC) tests on untreated specimens of plastic soil, which will serve as the control tests; (4) implementation of proposed mixing procedures, developed within each group, to prepare cement-treated specimens for UC tests; and (5) performance of UC tests on the cement-treated specimens to determine if the desired properties are achieved.

The core concepts are embedded within active learning exercises (ALEs), which are described in detail in the following subsections. It should be noted that one module session is designed for a full lab period, and it assumes that lab meets once per week. The complete module is designed such that the three sessions are consecutive, meaning that it spans a three-week sequence of a lab course. Each lab period is referred to as Module Session 1, 2, and 3.

Module Session 1A.

The first session begins with an interactive presentation on unpaved roads, which is the selected application for the core concepts that students will learn. The purpose of the presentation is twofold: first, it establishes a baseline for student understanding of unpaved roads and their global significance; second, it engages them in the identification of a meaningful problem. Two Think-Pair-Share (TPS) active learning exercises are embedded within the presentation. TPS exercises are designed for students to think independently about their answer(s) to a posed question(s), exchange their answers with another student, and then share answers with the entire class. The first TPS prompts students to consider where unpaved roads are found and what purpose those roads serve. It is followed with photographic examples that illustrate their usage in the U.S., but also highlights that unpaved roads are common worldwide. The second TPS requires students to reflect on the potential problems associated with unpaved roads. It is also followed with photographic examples of common problems, such as rutting and washouts.

The presentation concludes with the context for the EFFECT module, which is shown within the decision worksheet in Figure 1. The context must be crafted such that it facilitates student interest in achieving conceptual understanding (Pierce, 2016; Pierce et al., 2013). It was determined that the context would be set in a Third World nation, consistent with the global significance of unpaved roads. However, in the process of developing the module, two different contextual motivations were identified for stabilizing the unpaved road: (1) safe and rapid transport of U.S. military vehicles; and (2) safe and reliable transportation for local villagers to and from the nearest town. For the first implementation of the module, the latter context was chosen and presented as a potential Engineers Without Borders (EWB-USA) student project. The rationale was that the EWB-USA student chapter on our campus is active and most students are aware of its purpose. In the future, the effects of choosing different contexts should be evaluated.

Immediately after the presentation of context, students complete a decision worksheet as individuals and then in groups. Each group shares its estimation of cement needed and its cross-sectional sketch of the cement-stabilized road. Since the length and width of the road is specified in the problem (see Figure 1), the depth of treatment is an important variable, since it is required to calculate the total volume of soil. Based on the set of group sketches, a class discussion session is conducted to reach consensus on the depth of treatment for the road.

To close the discussion, students are prompted to provide some of the factors listed in response to the second supporting question (see Figure 1). Specifically, students are asked to associate the identified problems with unpaved roads with material learned in prior lab periods. It is anticipated that students will raise points for discussion about soil plasticity and the relationship between water content and Atterberg Limits, compaction, and stress-strain response. The purpose of the discussion is to stimulate and refine connections that students make between this supporting question (i.e., what do we need to know to solve this problem?) and other soil properties.

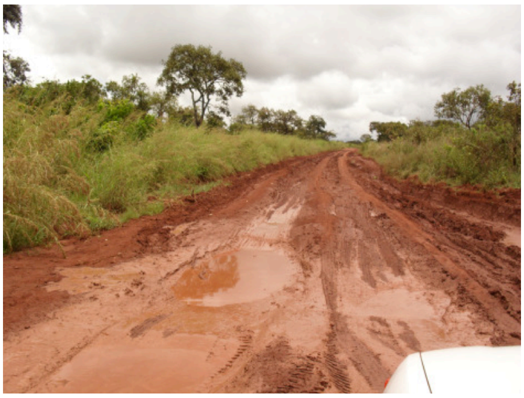
Module Session 1B.

The second part of the first session involves UC testing of untreated soil specimens, using a CL soil. Students are informed that this soil is representative of the soil that constitutes the unpaved road section described in the decision worksheet. Tests are performed on specimens compacted at two different water contents: near the liquid limit, LL; and at the optimum water content, w_{opt}.

The first specimen is prepared by the instructor at a water content just below its LL, and it is used for demonstration of the UC test method. With this specimen, students learn how to conduct a UC test; acquire raw data on axial load and deformation; calculate axial stress and strain; plot the stress-strain curve; and draw the Mohr's circle at failure. A worksheet is provided to the student groups to complete this active learning exercise.

Geotechnical Engineering Decision Worksheet: Unpaved Road Improvement

Most people think of roadways as being built with asphalt or concrete. Earthen materials (soil) can also be used to construct roads. Approximately 21.1 million miles (34 million kilometers), or 43%, of the world's road system is made up of unpaved roads. This value increases to 94% in Tanzania, whose roads serve an approximate 32 million people.



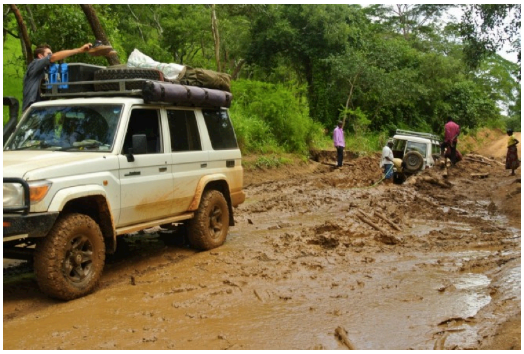
In Tanzania, rainy seasons are experienced from April to June and from November to December. Due to low shear strength and stiffness of the in situ soil and a large increase of moisture content during rain events, unpaved roads can fail, as shown in the two photographs.

As members of Engineers Without Borders (EWB-USA), your group has been selected to design and reconstruct a 16 feet wide, 1 mile long portion of an unpaved road near the town of Ngara. Since we are approaching the start of the rainy season, you will have three weeks to design the reconstruction. It is recommended that the required shear strength exceed 50 psi (345 kPa). Cement stabilization has been chosen as the method of improvement.

To design the reconstructed road section, the following driving question needs to be answered:

Driving Question:
How much cement (lbs.) is needed to achieve a shear strength of 50 psi for this 16 feet wide, 1 mile section of road?

Answer: _________ lbs.



To help answer this driving question, please complete the following four questions on the next sheet. You should answer the supporting questions before filling in the answer above.

1. On a sheet of engineering paper, sketch a cross-section of the road after it has been improved with cement. On the sketch, include dimensions and angles with appropriate units. Show where the cement is located, and explain how you think the cement should be added to the unpaved road.

2. What do you think is needed to make an accurate estimate of the amount of cement needed? List as many factors or pieces of information that you think are important for an accurate estimation.

3. For each one of the items listed in response to Question 2, make an assumption or approximation that will help you arrive at an initial solution.

4. Show calculations for the required weight of cement (lbs.).

Figure 1. Decision Worksheet for Module Session 1A

The second set of specimens is prepared to achieve maximum dry density at w_{opt}, as determined from compaction curves acquired in a prior lab period. Each group prepares a single specimen, compacting the soil into a nominal 5.1 cm by 10.2 cm cylindrical PVC mold using five lifts and 50 tamps per lift with a small, steel rod of known mass. All specimens are wrapped to prevent moisture loss prior to testing. Prior to performing UC tests on the specimens compacted at w_{opt}, students within each group complete a worksheet that focuses on stress-strain response. On it, each student must plot the *measured* stress-strain response of the specimen near its LL; *predicted* stress-strain response of the specimen at w_{opt}; and, lastly, the *measured* stress-strain response of that specimen. The predictions must include maximum stress, strain at maximum stress, and modulus of elasticity.

Module Session 2.
The second lab session of the module focuses on student-led selection of (1) cement dosage rates and (2) soil-cement lab mixing procedures. To determine dosage rates, an exercise worksheet is used that guides students to calculate the maximum amount of cement that can be acquired, based on the road dimensions and assumed depth of treatment. Students are informed that the maximum allowable dosage rate is 15% based on the available budget and treatable volume. This cap was set to help constrain the proposed solutions, rather than allowing no limitations. However, it was decided to set the maximum dosage rate higher than is needed to solve the problem, to see how that would influence the selection of the test matrix. As part of the worksheet, each group is prompted to indicate a range of dosage rates to be evaluated and, more specifically, to recommend five dosage rates for the test matrix. After a share-out session with the class, a consensus is reached on which five dosage rates to use.

Next, students participate in an ALE to determine the best procedure for mixing Portland cement with soil. In this exercise, students are provided with dried soil, cement, and deionized water to practice several different methods of mixing. Each one of four groups performs a trial mix under the following four conditions: dry mixing at a low cement content; wet mixing at a low cement content; dry mixing at a high cement content; and wet mixing at a high cement content. The fifth group observes all four of the trial methods and compiles the results to present to the class during a share-out session. The students are required to reach consensus on what method to use for mixing and how much water to incorporate. As part of this discussion, the explicit steps for soil-cement mixing are identified and documented on the board.

The final portion of this lab session requires each group to prepare a cement-treated soil specimen using the class-approved mixing method and the same compaction procedure as used for untreated specimens. Each one of the five groups prepares a specimen at one of the five cement dosage rates. Figure 2 highlights the mixing and compaction of soil-cement specimens. When completed, the compacted unit weight is calculated and the specimens are stored in a moisture closet for 7 days.

Module Session 3.
The third lab session concludes the EFFECT module with UC tests on cement-treated specimens. Prior to testing, students complete a worksheet similar to the one from Module Session 1B. This worksheet prompts the students to predict mechanical behavior of treated specimens compared to measured results from untreated specimens compacted near LL and at w_{opt}. After completing the worksheet, each group tests their prepared specimen and shares their experimental data with the other groups. An example of a specimen tested to failure is shown in Figure 2. Lastly, each group calculates maximum stress, strain at maximum stress, and modulus of elasticity for each cement dosage rate and compares the results. This completes the sequence of three lab periods dedicated to ground improvement.

3 IMPLEMENTATION

The EFFECT module was implemented in the Introduction to Geotechnical Engineering Lab during the spring 2016 semester. The course had an enrollment of 21 students, who were placed into five teams that worked together throughout the semester. This 1-credit hour lab course meets for three hours per week during a 13-week semester. It is offered concurrently with a 3-credit hour Introduction to Geotechnical Engineering lecture course. The lecture course is a core requirement, but the lab course is an elective. It is one of four lab course options from which students must select two.

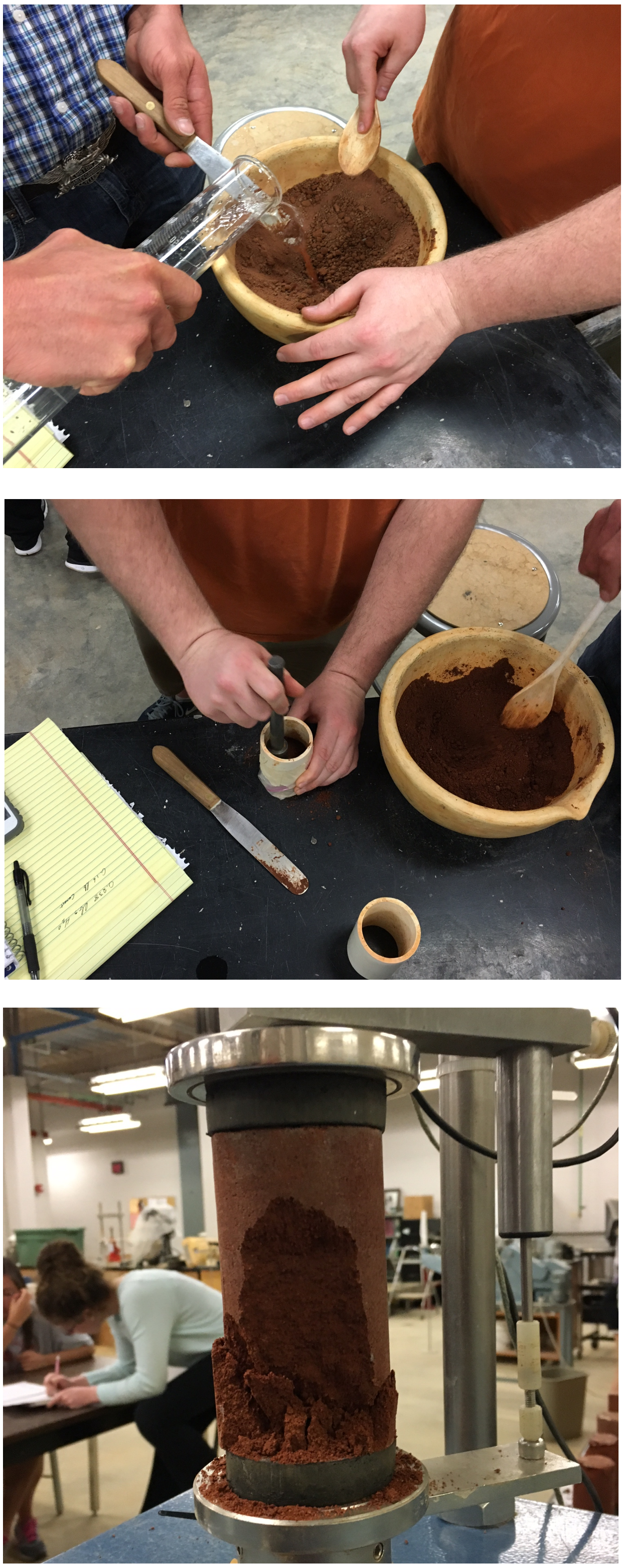


Figure 2. (top to bottom) Mixing; Compaction in Mold; Post-Test Failure of Specimen in Unconfined Compression

The module was designed to occur near the end of the semester, proceeding student learning of standard test methods common in most geotechnical lab courses, such as visual soil identification, grain size distribution, Atterberg Limits, standard Proctor compaction, and permeability. Table 1 identifies the week-to-week schedule, including the placement of the PBL sequence. There are two important observations regarding the lab schedule. First, most of the traditional tests were performed on the same plastic (CL) soil. Since this soil had been well characterized throughout the first half of the lab course, it was logical to incorporate it into the EFFECT module. This choice was also important for another reason, since it was intended for students to draw upon their knowledge of this particular soil to support their learning in the PBL sequence. Second, the EFFECT lab periods did not necessarily replace lab tests that are normally covered in this course. Rather, the EFFECT was used to enhance and improve the traditional lab period on unconfined compression. Historically, the remaining two lab periods are often set aside for lab demonstrations (e.g., 1-D consolidation, triaxial tests), field trips, and/or guest speakers. Thus, there was no loss of core content from the conventional approach to teaching this lab course.

4 OBSERVATIONS

The instructor and teaching assistant observed more consistent student engagement with the EFFECT module than with traditional lab experiments. When performing standard tests throughout the first half of the semester, students were often not engaged with the lab material except for the graded components, which included required pre-lab quizzes and writing the post-lab reports. In some cases, students were engaged during discussion of the test method and its significance. Even then, the engagement was limited. During lab exercises, students normally talked about things outside the class (e.g., homework for other classes, plans for the weekend, etc.) and only asked questions relevant to lab when confused about test procedures or data recording. During the module, however, student groups were commonly overheard discussing relevant terms and topics including in-place density, soil type, and water content. The teaching assistant provided the following comments comparing the EFFECT module to the traditional lab approach: *"In general, students were more engaged in the activities ... I believe the more students know about the concept of the test ... the more they will get from the class. Regarding the class, I would say it was planned perfectly and I believe this method would be more successful [than traditional labs]."*

One of the most significant reasons for increased engagement is the inclusion of multiple interactive activities, worksheets in particular, that students were required to complete as part of the solution to the problem. During classroom discussions, there was more student participation than usual, with a broader cross-section of students responding to questions posed by the instructor. In the more conventional setting, only a select number of high-achieving students would provide answers or feedback. Interestingly, the Think-Pair-Share activities were the most engaged and enthusiastic the students had been throughout the semester.

Throughout the PBL sequence, several students verbalized their interest in obtaining an answer to the driving question. In other words, students were motivated to solve the problem, and more importantly, were willing to share that sentiment openly with the instructor and teaching assistant. Specifically, one student kept stating that this problem *"will bother me over the next few weeks"* until she obtained a final answer. Students did not seem too discouraged that no answers were provided during the EFFECT lab periods, which would be deemed unacceptable during a traditional lab period. Lastly, and perhaps most significantly, most students remained engaged for the duration of the three-hour lab periods (i.e., being attentive to and observant of test procedures, collecting and comparing data, making calculations, etc.).

Table 1. Week-to-Week Schedule of Geotechnical Lab

Week No.	Lab Experiment	ASTM Standard	Test Soil			
			SW	SP	CL	CH
1	Visual-Manual ID	D2488	X	X	X	X
2	Sieve Analysis	D422		X	X	
3	Hydrometer Analysis	D422			X	
4	Atterberg Limits	D4318			X	
5-6	Compaction, Specific Gravity	D698 D854			X	
7	Constant Head Permeability	D2434	X	X		
8	California Bearing Ratio, Direct Shear	D1883 D3080		X	X	
9	EFFECT Period 1	D2166			X	
10	EFFECT Period 2	N/A			X	
11	EFFECT Period 3	D2166			X	
12	Lab Exam	N/A				
13	EFFECT Reports, Evaluations	N/A				

5 ASSESSMENT PLANS

There are no assessment data presented in this paper since the EFFECT module had just been completed at the time of publication. However, assessment plans include: (1) analysis of student evaluations, which were distributed at the end of the course; (2) compilation of student responses on the decision worksheets, and in particular, an assessment of student solutions to the driving question; (3) comparison of answers to the driving question on the decision worksheet and in the final reports; and (4) evaluation of conceptual understanding through content analysis of the final reports.

For consistency, final reports for the EFFECT module are expected to meet the same reporting requirements as throughout the semester. This format requires the following six sections: Objectives and Significance; Description of Materials; Experimental Procedures; Results; Analysis and Interpretation; and Conclusions.

In addition, the final report for the EFFECT module required specific information in three sections, as follows:

Experimental Procedures – Description of mixing and compaction procedures for untreated and cement-treated specimens.
Results – Presentation of maximum unconfined compression strength and shear strength of each tested specimen; stress-strain curves for each tested specimen; minimum dosage rate to reach required shear strength; and total amount of cement (lbs.) recommended to solve the problem.
Analysis and Interpretation – Discussion of *how* and *why* the answers changed from the decision worksheet to the final report, and what concepts the students learned that affected those changes.

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