Research-based and service-learning modules for undergraduate geotechnical engineering courses

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ABSTRACT: Four hands-on educational modules were designed for undergraduate geotechnical engineering courses at the University of Vermont; introduction to geotechnical engineering (Geotechnical Principles) and foundation engineering (Geotechnical Design). These modules were designed to incorporate inquiry-based learning and expose students to a systems approach to engineering education, which are the two major thrusts of an NSF funded curricular reform within the civil and environmental engineering programs. All modules were conducted within a group setting and required students to write technical papers in ASCE conference format or prepare a technical report and a presentation, with an additional underlying objective of the development of students’ interpersonal skills. Some statistical analysis and analytical and numerical modeling were required in some of the modules to expose students to information technology and understand the importance of coupling numerical and experimental methods. The educational modules included: (1) Atterberg limits using Casagrande and fall cone devices; (2) physical, analytical and numerical modeling of steady-state seepage; (3) validation of undrained slope stability, bearing capacity of shallow foundation and active and passive lateral earth pressure solutions using centrifuge modeling; and (4) service-learning projects related to foundations, retaining structures or slope stability for rehabilitation of historic structures. Integrated reflection and assessment activities were conducted. Student assessment results indicate that many of the curricular reform objectives are being successfully implemented.

INTRODUCTION

The civil and environmental engineering programs at the University of Vermont are undergoing NSF funded curriculum reform with a vision of creating an inquiry-based, environmentally-conscious undergraduate learning experience that prepares students in the following areas: (1) capable of adopting a systems approach to define and solve complex engineering problems, (2) skillful in information
technology, and (3) capable of becoming leaders in their chosen profession. At the core of the reform is the concept of service-learning. Service-learning projects generate meaningful work for the community while helping students develop interpersonal skills. They are open-ended in nature and promote a systems approach to engineering. Research-based learning is a form of inquiry-based, open-ended learning that promotes self-learning (e.g. Boyer Commission, 1998). One of the goals of our reform is also to include many hands-on activities because they develop a variety of investigative, organizational, creative, and communicative skills in students. An ancient Chinese proverb “I hear and I forget, I see and I remember, I do and I understand” sums up the importance of hands-on activities in any curriculum. Established learning theories such as Kolb’s theory of experiential learning (Kolb, 1984) have experimentation at their core.

Specific activities related to integrating inquiry-based learning have been implemented in the 3-credit undergraduate geotechnical engineering course, a requirement for civil as well as environmental engineering students in their junior year. Two open-ended exercises were introduced that required research on the students’ parts, and a third exercise will be implemented in Fall 2007. All three of these modules require either statistical, analytical or numerical modeling in addition to laboratory experiments and physical modeling. All three modules require students to write a technical paper, 6 to 8 pages long, in the ASCE conference paper format, to cultivate technical writing skills in students.

The first module is a research project where students conduct and analyze results of Atterberg limits tests on the same soil using both Casagrande and fall cone methods. The second module, involves the students constructing physical models of earth structures in tanks to observe seepage patterns and measure flow rate and piezometric heads at various locations in the models and verify the same quantities obtained from graphical and finite element based (using SEEP/W) solutions.

The third module is also based on physical modeling and is designed for the 3-credit foundation engineering course that follows the introductory geotechnical engineering course. The foundations course is a senior/graduate course and counts as a design or professional elective. It is not a required course, but is usually taken by about 20 students (a few graduate students with the majority being seniors). This module utilizes an instructional centrifuge to study stability problems, (e.g. slope stability, retaining wall and shallow foundation problems) to observe failure patterns and verify associated classical analytical solutions. The fourth module is a service-learning project, which is also part of the foundations course. Students work on evaluation and design of remedial schemes for historic structures with foundations, retaining structures or slope stability issues. The students are expected to devise their remedial schemes while maintaining the original elements of the structures as much as possible.

All modules are conducted in a group setting, with typically four to five students in each group. Papers, reports and presentations are prepared by each group with all group members as co-authors.

The four educational modules are described sequentially in the subsequent sections. Associated reflection and assessment activities and preliminary results of assessments are also discussed.
EDUCATIONAL MODULES

Module 1: Atterberg limits using Casagrande and fall cone devices

Students conduct Atterberg limits tests, liquid and plastic limits, on the same soil using two types of techniques; (1) Casagrande apparatus (commonly used in the U.S.) and (2) fall cone apparatus (used in Europe and Asia). The students share data from all groups (typically 10) and analyze in ways of their choice. They are graded based on the quality and depth of their analyses (e.g. statistical analysis on repeatability of results, is one method better than the other, operator dependence) and written quality of their technical paper. The project is worth 5 percent of the total course grade.

The purpose of this exercise, other than obtaining a greater knowledge of test methods and the Atterberg limits, is to understand that test results should not be accepted blindly. Traditional laboratory exercises on this subject have students obtain liquid and plastic limits for the purpose of soil classification. The tests are performed once, and the limits are taken by the students as absolute values without regard for the possibility of operator or experimental error. This traditional laboratory exercise is still done in the beginning of the semester with the research project as a follow-up project. This shows students that there are multiple methods for obtaining the limits, and that care should be taken in following experimental standards (e.g. ASTM) to obtain accurate and repeatable results. Most importantly, this exercise brings students through the process of collecting multiple sets of data, analyzing and presenting the data, as well as discussing and concluding meaning from the data. The project is relatively simple to conduct, so additional time can be devoted to writing the research paper in the ASCE conference format, which takes time because students find it quite different than writing a traditional laboratory report.

Module 2: Steady state seepage – physical model and graphical and numerical solutions

The second module allows student groups to construct physical models of hydraulic structures to study steady-state seepage. Five models are constructed and are shown in Figure 1. All seepage tanks are made of clear acrylic (similar to Elton [2001]) and are 7.5 cm wide. Their sectional dimensions range between 40 cm x 40 cm and 30 cm x 80 cm.

This project is conducted after the constant head and falling head permeability laboratory exercise is conducted and a written laboratory report is turned in. The students are asked to use the same sand and follow generally the same sample preparation procedure in constructing their flow model as the ones used in preparing the permeability test specimens, so the permeabilities can be used in the analysis of the flow models. In the permeability laboratory, students are also asked to conduct mechanical sieve analysis test on the sand to determine its effective size ($D_{10}$) to estimate permeability based on Hazen’s (1930) equation. Before the research project on seepage is conducted, a laboratory session on numerical modeling of steady state seepage is also conducted where students learn to use the finite element-based commercial software SEEP/W.
In the flow tank, a small network of tubes is placed in the bottom of the tank before the sand is introduced using light tamping. The model is saturated slowly under a small hydraulic head until the soil is saturated. Once the water starts appearing on the upstream soil boundary, small amount of sand is removed at three to four locations from near the acrylic front of the container. A small amount of potassium permanganate crystal is added in each of the slots. Water is then added from the top on the upstream and downstream soil boundaries. Constant water levels are maintained by utilizing overflows and a continuous water supply. The saturation process usually takes over half an hour. This time is usually sufficient for the students to record the actual model dimensions and draw a flow net and estimate flow rate, piezometric heads at some locations and exit gradient, if relevant.

It usually takes about 20 to 30 minutes for the flowlines to develop. The students then compare the observed flow patterns with those predicted by their hand-drawn flownets and later with computer outputs from SEEP/W. An example of such a comparison is shown in Figure 2. The students obtain the flow by measuring overflowing water from the downstream side over a specified time period. When divided by the width of the container, the flowrate per unit width is obtained. Students also measure piezometric heads at various locations in their model. These quantities are then compared to those predicted from the graphical solution and computer analysis. Students are asked to consider hydraulic conductivity data from their own constant and falling head tests, as well as from all other groups. The data from about 10 groups are over a reasonably wide range. This also illustrates how much variation can typically exist in the laboratory measurements of hydraulic conductivity. They are also asked to consider permeability based on Hazen’s equation.

This research project is also worth 5 percent of the total grade. Students are graded based the quality of their analyses, comparisons between experimental and analytical results, and quality of their technical paper.

This exercise stimulated student interest and created a visual representation of concepts learned in class. It also gave “meaning” to flow lines and flow nets and the concepts of piezometric head and exit gradient were made tangible by measuring the
heads. The students were also made aware of the three modeling techniques and the connections and differences between them, and how various techniques can be used to validate each other. The students also get to see five different sets of flowlines since in a given laboratory session, five different models are created. Student response to this research project has been very positive.

Module 3: Experimentation: Instructional Centrifuge

Inquiry-based research experiences continue in the follow-up design elective foundation engineering course. This module consists of three separate projects and will be introduced in Fall 2007. An instructional centrifuge was fabricated (Figure 3a) based on the instructional centrifuge at the University of Colorado at Boulder (Znidarcic, et al., 2007). The UVM centrifuge is equipped with a loadcell and displacements are obtained through analysis of digital images of the models. A large consolidometer (20 cm in diameter) was also fabricated to prepare large consolidated clay cakes for making centrifuge models. The centrifuge will be used to conduct educational research projects on the following stability problems: (1) undrained slope stability (Figure 3b) (validation of Taylor’s stability chart and limit equilibrium-based computer program SLOPE/W); (2) retaining wall (Figure 3b) (Rankine’s active and passive earth pressure theories); and (3) undrained bearing capacity (validation of Prandtl’s bearing capacity theory), as described by Dewoolkar, et al. (2003).

The foundation engineering course is a three-credit course, and there are no separate laboratory sessions. Classroom time will be used to conduct these experiments and research papers will be assigned as assignments, each worth 5 percent of final grade.

Figure 2: Physical model, graphical solution and computer output generated by students as a part of their research project on steady-state seepage

Figure 3: Instructional geotechnical centrifuge and centrifuge models
The primary purpose is to use centrifuge modeling as a tool for demonstrating geotechnical engineering concepts and not so much to teach about centrifuge modeling. Learning about centrifuge modeling technique is a by-product of the exercise. The experiments performed have proven to be very useful in the illustration of theoretical concepts taught in the class (Dewoolkar, et al., 2003). For example, students actually observe a circular failure surface in a model slope similar to the one assumed in the analysis. They do not simply have to take the teacher’s or textbook’s word for it.

Module 4: Service-learning: Geotechnical evaluation and remedial design

Service-learning is a form of experiential education in which students engage in activities that address human and community needs together with structured opportunities intentionally designed to promote student learning and development (Jacoby, 1996). It is a teaching and learning approach that promotes academic enhancement and personal growth through civic engagement.

Groups of four to five students are assigned a different historic structure in Vermont for a semester-long service-learning project conducted in the foundation engineering course. The projects span over 12 weeks and are worth 35 percent of the course grade. So far (2005, 2006), students have worked on shallow foundations, retaining structures and slope stability issues related to heritage facilities such as the one shown in Figure 4a. The projects have been with non-profits, such as the Preservation Trust of Vermont and Shelburne Farms. Typically, students survey the damage, study archived documents if available, conduct site investigations using hand augers and sampling equipment (Figure 4b), conduct in-situ borehole shear tests, occasionally assist in professional drilling activities (if the community partner can afford it), determine relevant soil properties (index testing and consolidation and shear strength testing using fully automated consolidation, triaxial and direct shear devices, Figure 4c), perform analysis, make recommendations for repairs, and prepare cost estimates. The experience is unique because students need to come up with remedial schemes while maintaining original elements of the structure as much as possible. The projects conclude with comprehensive project reports, presentations and student reflections. Representatives of community partners give the initial site visit, attend the mid-semester progress report and final presentations, and provide input. Such communication is important to ensure successful projects from the perspectives of the students, the instructor and the community partners alike. It is clearly communicated to the community partners that the analyses, designs and recommendations made by students should be checked by a registered professional engineer before adopting them.

These projects introduce students to the complex nature of engineering projects. They use the geotechnical skills they have obtained in their previous courses and the first part of the semester of this course to analyze problems and design solutions, but they are also introduced to the historic preservation, societal and economic aspects of the project. They take a systems approach to the problem, use new technologies, either testing equipment or modeling software, and interact with and present their findings to the community partners enhancing interpersonal skills.
INTEGRATED REFLECTION AND ASSESSMENT

Although many definitions of reflection exist, everyone pretty much agrees that reflection is essential to the learning process and improving retention of the academic material (e.g. Kolb, 1984). Reflection is a process designed to promote the examination and interpretation of experiences and the promotion of cognitive learning (Clayton and Moses, 2005). Evaluation is also an important component of the education process, both for the instructor and the student, for making improvements and determining success (or lack of success) in meeting objectives of the educational activity. The specific methods for conducting the assessments could be broadly divided into three categories: qualitative (typically suitable for formative evaluations), quantitative (typically desired for summative evaluations) and a mixed or combination method (NSF, 2002).

At the conclusion of the above modules students are asked to answer a relatively comprehensive questionnaire, which acts as an integrated reflection and summative assessment tool. Often, additional reflections are conducted through impromptu discussions in the classroom. Overall student attitudes towards the exercises conducted to date were positive. The students appreciated visually seeing the flow patterns. Overall, they found the projects to be a better experience than traditional laboratory assignments. Students agreed that the service-learning projects introduced them to the diverse nature of engineering problems and solutions, societal and economical aspects of engineering and the personnel involved. They definitely preferred the real-world service-learning projects to “made-up” projects. In fact, 7 out of 19 students in the course in Fall 2006 voluntarily responded to a question on their formal course evaluation “What did you like most about this course?” by answering “the service-learning project”.

CONCLUSIONS

The above exercises are not about simply teaching new tools. They are designed to help students understand the basics of research and the open-ended and complex nature of engineering projects, the importance of validating concepts and solutions, and above all, to learn the fundamentals so they are better prepared to lead complex projects in their careers.

The first two modules require minimal to modest resources. The exercises can easily be completed in a traditional two-hour laboratory session. The third module requires a more substantial investment into equipment, but the centrifuge can be
utilized in graduate courses and other research projects. Additional modules such as reinforced earth, trapdoor and contaminant transport can be developed. The service-learning projects benefited significantly from having access to the borehole shear tester and automated direct shear, consolidation and triaxial devices. Key soil properties could be determined relatively quickly, which resulted in expediting the progress of projects. So far, the community partners have adopted some of the low-cost recommendations made by students. At the very least, the student reports are used as a basis for planning purposes or more detailed analysis later.

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