Introduction to Geotechnical Engineering Using a Project-Based Module in a First-Year Engineering Course

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Abstract

While there are many references available to faculty that provide ideas and research related to teaching introductory geotechnical engineering courses, the author has found no reference that addresses a project-based introduction to geotechnical engineering that is suitable for a first-year introduction to engineering course. As part of a required first-year introduction to engineering course at Lafayette College, the author has developed and taught multiple offerings of a seven-week course that provides a low-cost framework for students to achieve student learning outcomes directly associated with geotechnical engineering in addition to the general engineering learning outcomes required for all sections of the course. The geotechnical learning outcomes associated with the module include demonstrating a basic understanding of the field of geotechnical engineering, the ability to develop a simple model related to the geotechnical performance of a structure, and the ability to conduct a simple analysis of risk. The author developed a three-week project within the course in which teams of students identify, document, analyze, and report on (in writing and orally) campus structures that are exhibiting distress related to settlement or other soil-related issues. Assessment of the achievement of the geotechnical student learning outcomes in the course was conducted by analyzing student-generated concept maps and rubrics created for the project reports and presentations. Assessment results provide evidence that the seven-week course, including the three-week geotechnical module, successfully supports the general engineering learning outcomes and the geotechnical learning outcomes associated with the course.

Introduction

Engaging engineering students with authentic aspects of engineering early in their coursework has been shown to increase student retention and success[1,2]. Because of these benefits, incorporating authentic projects is often considered in the development of new introduction to engineering (ItE) courses. Extensive literature regarding teaching first-year engineering courses is available and much of that work is documented within the publications of ASEE's First-Year Programs Division (work which is too numerous to reference here). Within that body of work, recent work has been done concerning the classification of ItE courses by Reeping and Reid[3,4]. Reeping and Reid's work looked at a preliminary data sample of 28 ItE courses and analyzed course content with respect to eight main outcomes: communication, engineering profession, math skills and applications, design, global interest, professional skills/latent curriculum, academic success, and engineering specific technology/tools. Reeping and Reid's work indicates that while nearly all ItE courses include design as a topic, less than a quarter include authentic design and less than half of these design-focused courses include hypothesis testing, modeling, or realistic problem formulation/solving as learning outcomes.

In the development of a new ItE course at Lafayette College, the author wanted to include an authentic engineering experience related to geotechnical engineering that included student learning outcomes related to hypothesis testing, modeling, and realistic problem formation. This paper provides background regarding the offering of ItE courses incorporating a geotechnical engineering project, a description of the course developed by the author, and preliminary assessment of the educational outcomes related to the course.

Background –Geotechnical Projects in ItE Courses

While Reeping and Reid's work provides insight into the nature of ItE courses across the United States, the author found no published information on the use of geotechnical engineering projects in ItE courses. Therefore, the author conducted a survey to determine whether geotechnical faculty in the United States were using or had used geotechnical project-based approaches within ItE courses. Using email, the author asked members of the United States Universities Council on Geotechnical Education and Research (USUCGER) to respond if they were using or were aware of other geotechnical faculty using geotechnical projects within ItE courses. USUCGER was founded in 1985 as an advocacy group for the high quality research and education in geotechnical engineering (see www.usucger.org.) USUCGER currently has 132 member institutions representing the majority of geotechnical engineering faculty in the US.

Only four responses to the survey provided information on institutions that currently or in the past have incorporated geotechnical projects into ItE courses (not including the course and project described in this paper). The projects at each of these institutions were all similar to the Geo-Institute's annual GeoWall competition (students.geoinstitute.org/geochallenge). The GeoWall competition is a yearly event at the regional and national level where teams of students design, build, and test a model retaining wall fabricated using paper as the reinforcing material. The wall is designed to support a range of different loading scenarios. The project, simplified to reduce the time involved and to allow for construction and testing to be integrated into an ItE course, is an excellent way to introduce students to geotechnical engineering design and the author considered developing a similar project for her course. However, limited resources (scheduled in-class time, lab availability, and funds) made the project infeasible for the author's course.

Institutional Context and Course Description

Lafayette College is a strictly undergraduate institution with four B.S. engineering programs (civil, mechanical, chemical, and electrical and computer engineering) and all first-year engineering students (approximately 200 each year) are required to take an ItE course. The ItE course has the following catalog description:

> *This course teaches the fundamentals of engineering design methodology. Students will use engineering design processes to aid them in: recognizing the need for an engineering solution, defining constraints, specifying requirements, and modeling an engineering solution, among other aspects of engineering design. Instructors integrate societal contexts of engineering practice into the projects and examine the implications of engineering solutions.*

During the semester, students in the course take two seven-week modules with topics related to two different disciplines of engineering. The classes meet with a member of the engineering faculty for three 75-minute sessions each week and enrollments are capped at

20 students. The student learning outcomes developed by consensus of the engineering programs are the same for every module. At the end of the course, students are expected to be able to

- recognize that engineering during college and beyond is innovative and exciting and
- understand the design process.

In addition, each faculty member is also expected to develop his/her module such that students

- have an introductory design experience;
- have experiences using engineering equipment, tools, software, and hardware appropriate to the topic of the course;
- have an introductory understanding of the societal context of engineering relevant to the topic of the course; and
- gain experience in visually and orally conveying engineering information.

In addition to classes with members of the engineering faculty, students also complete sessions in graphics with a separate instructor and are required to attend a number of co-curricular activities.

Faculty members teaching the course have taken a range of approaches to have students obtain the desired learning outcomes. Brief descriptions of a few modules are listed below (paraphrased from materials provided to incoming students).

Essential MATLAB for Engineers: This module introduces the software package MATLAB and students solve mechanical, electrical, chemical, and civil engineering problems using MATLAB. A design project from any of the engineering disciplines implemented using MATLAB is assigned.

The Art of Engineering Small: The engineering and underlying science of building small will be developed in hands-on learning exercises and applied to a design experience focused on inexpensive, reliable, and rugged medical diagnostic technologies which contemplate social contexts and constraints for the developing world.

Engineering Design—Why Structure Stand Up and Fall Down: This module will introduce students to the engineering concepts (material behavior, force analysis and dynamic response) that are at the heart of designing structures, machines and products. Students will build a physical model and load test it to failure.

Designing the Sustainable City: Students will use our city as a laboratory to apply principles of reverse engineering to understand existing infrastructure and apply the design process to develop creative solutions to urban infrastructure problems.

Geotechnical Engineering Module

The author wanted to provide students with a meaningful introduction to civil engineering and specifically to geotechnical engineering that would align with the structure of the course and its required learning outcomes. In addition to the student learning outcomes listed above, the author added the following outcomes:

- demonstrate a basic understanding of the field of geotechnical engineering;
- develop a simple model related to the geotechnical performance of a structure;
- conduct a simple analysis of risk; and
- write a geotechnical report in standard format.

To have students achieve these outcomes as well as the general course outcomes, the author developed the schedule shown in Table 1.

Week	Topics Covered/Activities Conducted
1	Introduction to course; design thinking exercise developed by Stanford's Design School (http://dschool.stanford.edu/use-our-methods/)
2	Engineering communication (memos, reports, presentations); introduction to civil engineering and design/construction in the urban environment; graphics session
3	Introduction to soil and rock as engineering materials; introduction to foundation design and performance; structural tolerances for movement; graphics session
4	Terzaghi's observational method; simple measuring tools; estimating risk; campus survey of distressed structures
5	Project selection; in-class project work; meetings with instructor
6	In-class project work; meetings with instructor
7	Practice presentations; final presentations; module wrap up

Table 1: Schedule for Seven-Week Course Module

At the beginning of the module, the author used lectures and videos to provide students with an overview of the design process, civil engineering, and how geotechnical engineers consider and use soil and rock as engineering materials. This overview included information regarding different types of foundations, conceptual models for foundation capacity and settlement, structural tolerances for movement, and Terzaghi's observational method. The author also gave students instruction in and opportunities to use simple measuring tools including tape measures, plumb bobs, and a water level. In addition, the author introduced the development and use of event trees as a simple method to estimate risk.

The last three weeks of the module were devoted to the geotechnical project. The key elements of the geotechnical project are described below.

Campus survey of distressed structures: During a normally scheduled class, students were randomly paired into teams and were asked to explore the campus and identify five structures that appeared to be exhibiting distress that might be caused by settlement. The students were asked to take photographs of the distress, to hypothesize what might be causing the problem, and to consider what risks the distress might cause both in its current state and if the distress became progressively worse.

Project selection: During the class following the campus survey activity, each team of students presented the information they had collected. The author then facilitated a discussion regarding the potential causes for the distress and the potential risks. At the end of the class, each team of students rank-ordered the structures they had identified with the structure that they were most interested in studying further being ranked first. The author then assigned each group a project based on their preferences but insuring that in each section of the course, no two groups were studying the same area of structural distress.

Project assignment: The author asked the students to complete the following for their projects:

- Document the current state of distress of the structure using simple measurements, sketches, and photographs. Students were asked to document the distress with sufficient detail and accuracy so that their findings could be used in six to twelve months as a basis for a new team of students to determine whether the distress had developed further. Simple tools, including tape measures, plumb bobs, and water levels, were provided.
- Identify at least two triggering events that might cause the observed distress to increase (e.g., placement of a large load on or near the structure) and, for each triggering event, develop simple event trees to estimate potential levels of risk to the structure, its occupants, and/or its users.
- Summarize their findings in a report to the client (the course instructor). The rubric for the report is provided in Appendix A.
- Prepare and give a presentation to the class on the project. The rubric for the presentation is provided in Appendix B.

In-class project work: Students were given seven scheduled class-meeting times to work on their projects. During two of the class meetings, each group met formally with the instructor. At the first of these meetings with the instructor, the group shared the documentation they had completed for their structure and received instructor feedback. At the second meeting they discussed and shared the event trees they had developed and received feedback. During the other class meetings, the author held "office hours" in the back of the classroom and student groups could ask questions and get feedback on their draft materials.

One class period during the in-class project work sessions was devoted to trial runs of the student presentations. During the trial runs, students in the class convened in the hallway outside the classroom and the instructor called in individual teams so that each team could give their presentation and receive feedback. This was also an opportunity for the students to check that their presentations worked with the technology provided in the classroom. (For many of the student teams this was their first presentation in one of the College's smart classrooms.)

Presentations and Submission of Final Reports: Final presentations were given to the full class with time for questions. Each team submitted their final written report at the class meeting following their presentations.

Results

The student teams identified a number of campus structures showing various degrees of distress that may have resulted from settlement—this type of distress was surprisingly easy to find on the campus and similar results might be anticipated for any campus with a significant number of masonry structures and/or retaining walls. In addition to structures, one student team identified and studied a significant depression that was located adjacent to a structure (the campus is located in an area where sinkholes are common).

Once the student teams had identified the structures for their projects, the in-class meetings provided sufficient opportunities for the students to take measurements of the distress, develop and receive feedback on their documentation of the distress, and to develop and receive feedback on their hypotheses and analysis of possible triggers and risks posed by the distress. All groups needed additional time outside of class to write their reports and to develop their presentations.

The final presentations were nearly uniformly evaluated as strong work (see Appendix B) and students commented that the opportunity to receive feedback on the trial presentation was particularly helpful. From the author's perspective, the presentations indicated that most students felt ownership and pride in their work. The final reports on average represented work that had strong elements but in many areas still needed development (see Appendix A). In future offerings, the author will modify the schedule so that there is one day for in-class peer review of draft reports. The author believes that this additional step will allow students to receive feedback from student peers and will provide students with an opportunity to read reports from other groups and to see how other teams present their results.

Assessment of the course outcomes was done using the rubrics completed for the project reports and presentations (see Appendixes A and B) and a comparison of student concept maps drawn at the start and at the end of each module. There are many resources available that describe the use of concept maps as an assessment tool5 (e.g., Stoddart et al. 2000[5] and Ingec 2009[6]) and further discussion of this approach is beyond the scope of this paper. The concept map assignment used in the class is presented in Appendix C and the rubric used to evaluate the maps is presented in Appendix D. Table 2 summarizes the assessment results.

Student Learning Outcome	Assessment Method	Assessment Result
Demonstrate a basic understanding of the field of geotechnical engineering	Comparison of student concept maps created at start and end of module using rubric	Average rubric scores related to "non-trivial understanding of at least one area of engineering" increased from an average of 0.37 to 1.17.
Develop a simple model related to the geotechnical performance of a structure	Evaluation of content of final project reports.	100% of students achieved this outcome.
Conduct a simple analysis of risk	Evaluation of content of final project reports and presentations	100% of students achieved this outcome.
Write a geotechnical report in standard format	Evaluation of content of final project reports.	100% of students achieved this outcome.

Table 2: Summary of Assessment Results

Conclusions

The three-week geotechnical project developed by the author for the ItE course successfully achieved the desired student learning outcomes related to geotechnical engineering. There were no significant challenges associated with the project; however, to improve student writing, an additional day could be added to the project to provide opportunities for peer review of draft reports.

The project provided many benefits beyond the achievement of the desired learning outcomes including low cost, easy course preparation, significant student interest and engagement, and improved student knowledge of the campus. It is hoped that the project will increase interest and retention in the civil engineering program and specifically increase interest in geotechnical engineering but further study will be required to determine the long-term impact.

References

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[3] Reid, Kenneth, and Reeping, David (2014). "A Classificaton Scheme for 'Introduction to Engineering' Courses: Defining First-Year Courses Based on Descriptions, Outcomes and Assessment," *Proceedings of the American Society for Engineering Education Annual Conference*.

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[6] Ingec, S. K. (2009). "Analysing Concept Maps as an Assessment Tool in Teaching Physics and Comparison with Achievement Tests," *International Journal of Science Education*, 31 (14), 1897-1915.

Appendix A: Rubric for Final Reports

Category / Scale	Strong Work	Needs development	Unsatisfactory
Overall Format / Appearance / Organization	• Report follows required format. • Organization of space (e.g., use of white space) and the choice of font look professional and permits easier reading		
Cover Memo	• Effectively communicates the transmission of the report from the team to the instructor.		
Summary	• Includes the purpose of the report • Includes an outline of the key issues studied, • Includes an outline of the main conclusions / recommendations		
Introduction	• Describes the project in general terms • Provides an overview of the report's organization		
Documentation of Observed Structural Distress	• Effectively describes the location of the distressed structure • Effectively documents the observed distress so that future movements can be detected		
Analysis and Results	• Clearly describes evaluation process used • Clearly communicates results of analysis • Effectively discusses related uncertainties		

Category / Scale	Strong Work	Needs development	Unsatisfactory
Conclusions / Recommendations	• Clearly presents conclusions / recommendations • All conclusions / recommendations are supported by information presented earlier in the report.		
References (if used)	• Follow APA format		
Figures/Tables	• Have unique identifying numbers • Have descriptive titles • Present information in a clear / concise manner		
Paragraphs	• The topic of each paragraph is clear. • Transitions between paragraphs are clear and smooth. • Paragraph length is generally short but there is some variation.		
Sentence fluency	• Sentences are clear, complete, and of varying lengths.	• Writer's sentences are sometimes awkward, and/or contain run-ons and fragments.	• Many run-ons, fragments, and awkward phrasings make writer's essay hard to read.
Word choice	• Word choice is appropriate to the context, and the word choice enhances meaning.	• Writer makes a number of word choices inappropriate to the context, which disrupts meaning.	• Writer makes many word choices inappropriate to the context, which significantly disrupts meaning.
Mechanics	• Writer uses correct grammar, spelling, and punctuation – no errors.	• Writer generally uses correct conventions, may have a couple of errors that could be easily fixed.	• Writer has enough errors in essay to distract a reader.

Papers deserving an A grade will be strong in nearly all areas and have no unsatisfactory elements; papers that are strong in the majority of areas and have no unsatisfactory elements will receive a B; a grade of C reflects a need for development in most categories; D work is typically unsatisfactory in about half of the categories; and F work is unsatisfactory in the majority of categories.

Appendix B: Rubric for Final Presentations

Category / Scale	Strong Work	Needs development	Unsatisfactory
Introduction	• Identifies speakers and their roles in the presentation • Describes the project in general terms • Provides an overview of the presentation's organization		
Description / Documentation	• Effectively describes the location of the distressed structure • Effectively documents the observed distress		
Analysis	• Effectively presents hypothesis for cause of distress • Effectively presents potential concerns raised by the distress • Clearly describes evaluation process used		
Results	• Clearly communicates results of analysis • Effectively discusses related uncertainties		
Conclusions / Recommendations	• Clearly presents conclusions / recommendations		
Visuals	• Visuals were well organized, aligned with the oral presentation, and were easy to read / understand		
Oral Presentation Skills	• Confident, comfortable delivery – speakers appeared natural and conversational • Good fluency of speech – appeared as if they well-rehearsed • Expressed interest in the topic and appreciation of / connection to the audience		

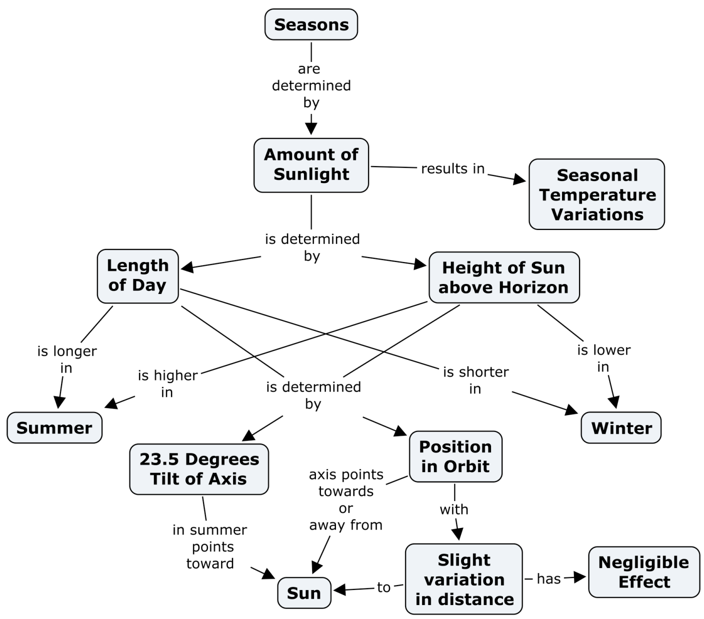
Presentations deserving an A grade will be strong in nearly all areas and have no unsatisfactory elements; papers that are strong in the majority of areas and have no unsatisfactory elements will receive a B; a grade of C reflects a need for development in most categories; D work is typically unsatisfactory in about half of the categories; and F work is unsatisfactory in the majority of categories.

Appendix C: Concept Map Assignment

Concept Map Assignment

Concept maps are drawings that illustrate relationships between ideas and/or concepts and are often used by engineers to organize their knowledge of a subject—i.e., they are a visual method of organizing information. In a concept map, each word or phrase connects to another and links back to the original idea or concept.

An example of a concept map is shown below.



For this assignment, I want you to develop a concept map for "Engineering" (i.e., a map that in visual terms answers the question, "What is engineering?")

- Brainstorm for a few minutes and, on the back of this paper, write down terms and short phrases that are connected to your current understanding of engineering.
- On a new sheet of paper, draw a concept map based on your brainstorming, placing "Engineering" at the center or top of the drawing and drawing lines to other related concepts.
- After you have sketched in the primary associations, move on to add secondary or tertiary levels of association (or more), if appropriate.
- Determine the ways in which the various concepts are related to each other and write those types of relations on the lines connecting the concepts.
- Put your name on the map and turn it in!

Appendix D: Rubric for Evaluation of Concept Maps

Element	Score		
	0	**1**	**2**
Design is an integral part of engineering	No mention of design concepts	Design concepts are present in map but have few if any meaningful connections	Design concepts are present in map and have multiple connections
Design requires empathy with users	No indication of recognition of need for empathy	Map includes minimal recognition of need for empathy	Map indicates a clear connection between empathy and the design process
Design as an iterative process	Design is not conveyed as being a process	Design is conveyed as being a process but is not shown as iterative	Design is conveyed as being an iterative process
Engineering is innovative/exciting	No use of words displaying affect	Limited use of words displaying affect	Map uses terms displaying affect to convey innovation or excitement
Non-trivial understanding of at least one area of engineering	No indication of depth of understanding in any area of engineering	Limited indication of depth of understanding in at least one area	Multiple map links indicate depth of understanding of at least one area of engineering
Understanding of multiple areas of engineering	No indication of recognition of basic fields of engineering	Indications of basic fields of engineering present but limited elaboration provided	Indications of basic fields of engineering present and connections indicate non-trivial understanding of multiple areas