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TEACHING ENGINEERING LITERACY TO NON-ENGINEERING STUDENTS IN FORMAL LEARNING ENVIRONMENTS

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Abstract: Since enrollment rates in American college engineering programs have been constantly dropping, formal and informal processes to teach and learn engineering are on the rise. An opportunity actually exists to formally teach engineering to construction students in US colleges and universities. If non-engineers understand how science and technology work, they can better interact with scientists and engineers in the workforce and make informed decisions about when technology can be a solution to a problem, or when other solutions maybe more adequate. To this date, higher engineering education has been repeatedly investigated through the lenses of engineering programs and degrees. This paper investigates engineering literacy for non-engineering students, by comparing the performance of engineering and non-engineering students when gaining engineering literacy. The methodology of this study consists of analyzing the performance of construction management (CON) and civil and environmental engineering (CEE) students in comparable courses taught in both programs: introduction to geotechnical engineering and geotechnical applications. Data is collected over four distinct semesters. The results reveal that CON students scored significantly higher grades when the course was offered from a non-engineering perspective rather than from an engineering perspective. The results of the study highlight the need to develop clear and consistent teaching methods and techniques that take non-engineering students' diverse backgrounds into consideration.

1 MOTIVATION

Over the last decade, enrollment rates in American college engineering programs have been dropping constantly. The U.S. ranks well behind other countries in the percent of students earning their first university degree in engineering or science. In the U.S., 15% of undergraduates receive degrees in natural science or engineering compared to 38, 47, 50 and 67% in South Korea, France, China, and Singapore, respectively (AIAA 2003). Given that technological innovation is a key ingredient to economic growth and high paying jobs, the U.S. is in critical need of more engineers, especially with the acceleration of engineers' production in countries such as China (NSF 2010). Because the U.S. is losing its competitive advantage in science and technology, leading business organizations set a goal of doubling the number of bachelor's degrees in science, technology, engineering and mathematics (Business Roundtable 2005).

Engineering affects all disciplines in many ways. Since many managers, directors, and policymakers are making decisions related to key technology-based issues, it makes sense to provide them with a conceptual framework of technology (Mina 2007). Because the decisions that engineers make regarding infrastructure and consumer products involve almost everybody, even students enrolled in non-engineering curricula can benefit from examining engineering issues (Dyrud 2001). In today's globalized world, engineering teams frequently comprise key individuals with non-engineering Science, Technology, Engineering, and Math (STEM) backgrounds. While not yet common, some engineering departments offer service courses for non-engineers (Krupczak and Ollis 2006). Examples of such science and technology programs that require engineering literacy include programs in computer technology, informatics, construction, environmental and biomedical sciences, aeronautical, industrial, architecture or graphic design. These science and technology programs, and many others, require students to learn engineering and design principles. The National Academy of Engineering is advocating that all Americans need to better understand all types of technology, not just computers and information technology (Pearson and Young 2002). A survey of the literature shows a positive perception towards engineering content (Krupczak et al. 2005). Scholars addressed the success of several programs and courses across the U.S. in attracting non-engineering students to engineering fields (Nahapetian 2011). These programs provided technological awareness and an understanding of technical issues to non-engineering students to develop basic literacy in engineering. Mina (2007) summarized the main incentives behind students enrolling in engineering courses: (a) to better understand the role of engineering in society and the interactions of engineering with their major field of study; (b) perform simple calculations and estimations using engineering methods; (c) make cost-benefit and risk-benefit analyses; (d) appreciate the importance of the underlying assumptions used to produce the cost-benefit and risk-benefit analyses presented by engineers; (e) make informed decisions about the desirability of engineering activities by weighing the benefits of those activities against their environmental risks; (f) understand the interdependence of the economic, environmental, and sociological aspects of technological change; (g) assess the validity and possible weaknesses in predictions of economic, environmental, and sociological consequences of technological change presented by others; (h) attain a basic understanding of the engineering design process; (i) achieve a survey-level understanding of why particular materials and processes are used to produce simple engineering devices and systems; and (j) understand the capabilities and limitations of basic manufacturing processes and engineering systems.

The inclusion of non-engineers on an engineering service learning project can significantly alter the manner in which the participants view the impacts of an engineering project. In general, engineers tend to seek quantitative solutions to a given problem, while non-engineers, particularly those who are from the liberal arts, will seek more qualitative solutions, most often addressing the impacts of the proposed engineering solutions (Polito 2005). However, the non-engineering students need specially-developed courses that take their backgrounds and skills into account. Developing and teaching non-engineering courses requires a different approach from the traditional way courses are taught to engineering students (Sadiku and Yantorno 1997). If non-engineers understand how science and technology work, they can better interact with scientists and engineers in the workforce and make informed decisions about when technology can be a solution to a problem, and when other solutions may be better. It is important that non-engineers understand enough about science and engineering so that they can apply technology where it is most useful to society (Nickels and Giolma 2000). Hence, it is the responsibility of engineering faculty to develop such courses with the intended audience and desired course outcomes in mind (Mahajan et al. 1996).

So far, the challenges associated with providing a solid engineering professional development framework for non-engineering degree seekers have not yet been tackled. To this date, higher engineering education has been repeatedly investigated through the lenses of engineering programs and degrees. However, creating an inclusive environment so that the significant mass of students in multiple technology and science programs can effectively learn core design and engineering principles has yet to be tackled. This paper aims to act as a first building block by comparing the performance of engineering and non-engineering students when gaining comparable engineering literacy.

2 RESEARCH METHODOLOGYMETHODLOGY

A statistical analysis on student performance on two parallel undergraduate courses in introduction to geotechnical engineering applications serves to compare the performance of engineering and construction management students. Indeed, two separate classes, with common learning and performance outcomes, are taught each semester for both engineering (civil engineering) and non-engineering (construction management) students by two instructors with PhD degrees in civil engineering and with similar backgrounds. Students who successfully complete both courses have a broad understanding of soil mechanics principles related to construction. Some of the topics discussed include: rocks/geology/soil formations, deep foundations, soil classification, USCS & AASHTO, site investigations for construction, soils reports, consolidation, settlement, compaction, stresses in soils, surface loading, shear stress and Mohr's circle, lateral soil loads, retaining walls, overturning, bearing capacity, and shallow foundations. Moreover, the performance of students in the two classes will be assessed similarly. The grade will consist of homework assignments on the various topics, a project paper, and three exams.

The methodology of this study consists of collecting anonymous performance scores of construction management (CON) and civil and environmental engineering (CEE) students enrolled in the course over four distinct semesters. For each class, the anonymous data was provided by the Academic Advising office, which keeps grade records for all classes. First, the paper compares student characteristics. Second, the paper compares the performance of CON and CEE students and tests the statistical significance of the results using an unpaired t-test with unequal variances. The tested hypothesis is that the average grade of CON students (x) is equal to that of CEE students (y). This assumption is tested, at a 95% confidence level, for the null hypothesis (H_0) or its alternative (H_1) as follows:

- H0: x = y if p-value is greater than 0.05; the null hypothesis is engineering and non-engineering student performance is similar;
- H1: x≠y if p-value is less than 0.05; then we have evidence to reject the null hypothesis.

Third, the paper examines the factors that could affect student performance in different semesters and tests the statistical significance of the differences using ANOVA tests. The paper ends with a discussion of the results and raises several critical engineering education questions for future studies.

3 RESULTS AND DISCUSSION

This section presents the results of the comparison between engineering and non-engineering students enrolled in the geotechnical course, and leads to a discussion of the potential parameters that could explain the differences in performance between both groups of students. Of the 381 students, 255 are engineering students and 126 are non-engineering students (see Table 1). Figure 1 illustrates comparable percentages for CEE and CON students in the four studied semesters.

Table 1: Characteristics of CEE and CON students

Semester	CEE	CON
1	64	28
2	59	42
3	81	26
4	51	30
Total	255	126

Next, Figure 2 shows a difference in female and male student percentages between the CEE and CON students. While only 10% of CON students are females, this percentage is three times higher for CEE students. The number of women studying engineering and technology is quite low relative to other previously male-dominated professions such as law and medicine. The low percentage of women in CON in this current study is comparable to national percentages.

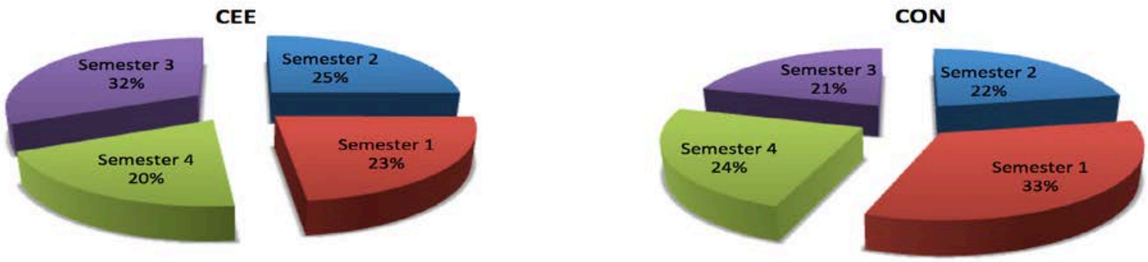

Figure 1: Split percentages between CEE an CON students

For example, the percentages of electrical and mechanical engineering degrees awarded to women in 2009 were also very low, sitting at just 11.5% and 11.4%, respectively (American Society for Engineering Education 2010).

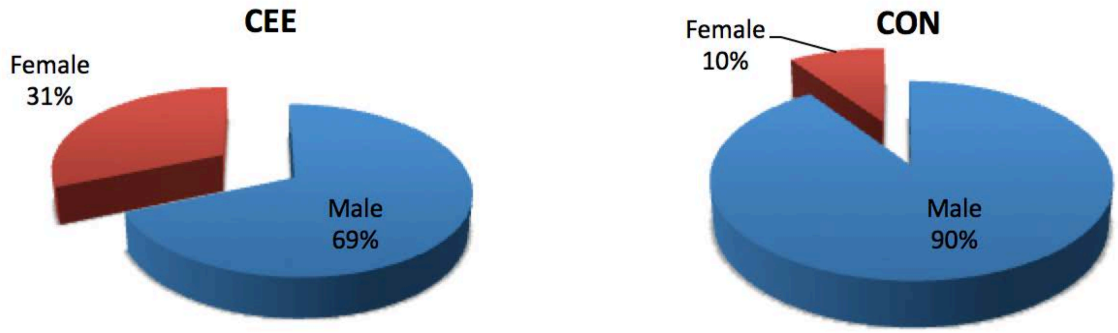

Figure 2: CEE and CON students' female/male distribution

Figure 3 provides a graphical illustration of the differences in grades between CEE and CON students, in the form of boxplots. CON students seem to score slightly higher grades, and the statistical testing of the results confirms this difference in performance. The top of Table 2 shows the t-test p-value is smaller than 0.05, which leads to rejecting the null hypothesis. Therefore, the observed differences in performance are statistically significant.

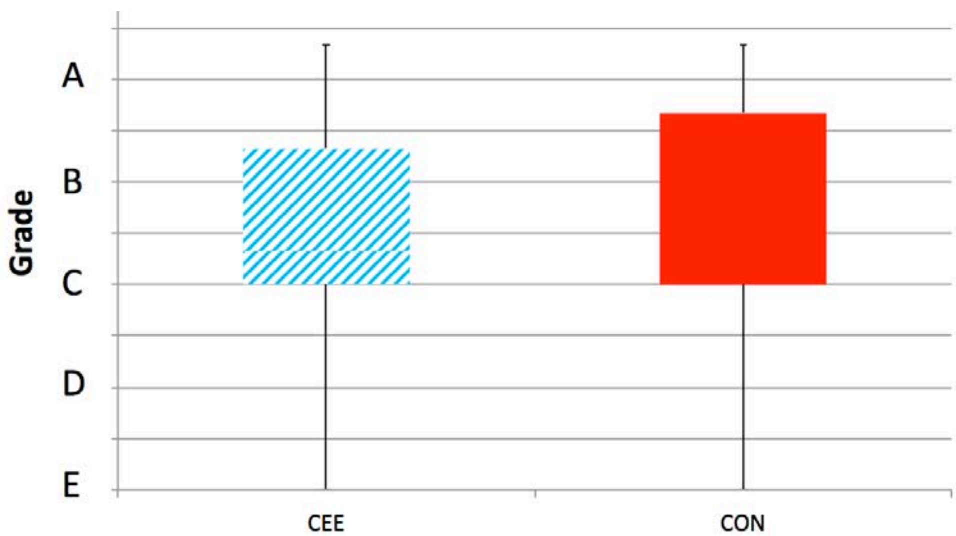

Figure 3: CEE and CON overall grade distribution

For a better understanding of the parameters that might affect the performance of CEE and CON students in the studied course, a closer examination of the grades for each semester is needed. After conducting ANOVA tests on the data and checking the significance of the differences, the results are illustrated in Figure 4 below. Except for one semester, CEE and CON student performance was similar. One of the reasons that explain the difference in CON students' performance between semesters 1, 2, 3, on one hand, and semester 4 on the other hand, is the manner in which the course was taught. Table 3 summarizes the covered topics when the course is offered from: (i) an engineering perspective (semesters 1, 2, 3) by focusing deeply on quantitative engineering and design principles; and (ii) from a non-engineering perspective that offers a broad understanding of engineering principles with an emphasis on the practical and contractual points of view (semester 4). CON students performed much better when the course was offered from a non-engineering perspective, which catered to the students' diverse and often non-quantitative backgrounds. While the difference in teaching methods justifies the variance in the results, other interrelated factors also may have major impacts on the performance of non-engineering students in engineering courses, including: student background, instructor background and experience, program pre-requisites, interactive teaching tools and support. The results of this study lay the foundation for a future study to explore the combination of reasons behind this noticeable variation.

Table 2: Statistical analysis – t-test (top) and ANOVA (bottom)

		CON	***CEE***
T-Test	**Mean**	2.71	2.44
	Variance	1.11	1.07
	Observations	125	254
	P(T<=t) two-tail	0.02	
	t Critical two-tail	1.97	

	Source	**SS**	**df**	**MS**	**F**	**P**
ANOVA Test	**Semester**	30.28	3	10.09	10.11	<.0001
	Class (CEE/CON)	9.79	1	9.79	9.8	0.002
	Combination	14.51	3	4.84	4.84	0.003
	Error	372.5	373	1		
	Total	414.3	380			

This study also raises several questions: (1) What teaching methods and techniques are appropriate for ensuring non-engineering students gain adequate engineering literacy? (2) How can we ensure engineering instructors are best prepared to teach engineering courses to non-engineering students? (3) What are the key learning barriers for non-engineering students to become engineering literate? Additional research is needed to answer these critical engineering education questions.

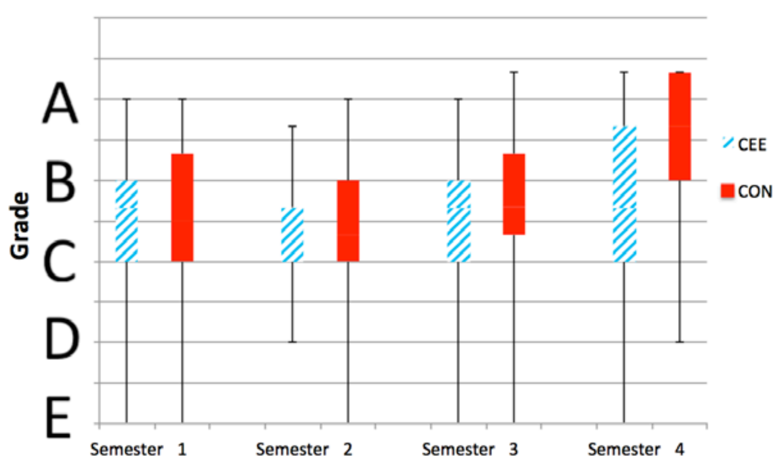

Figure 4: CEE vs. CON students' grades per semester

Table 3: Covered topics in the course

	Semester 4	Semesters 1, 2, and 3
Textbook	*Principles of Geotechnical Engineering*, Thompson Learning by Braja Das and Khaled Sobhan	*Soils in Construction*, Pearson/Prentice Hall by WL Schroeder, SE Dickenson, and Don C. Warrington
Outline	Course Overview and Introduction	Course Overview and Introduction
	Geotechnical Failures	Physical Character of Soil Constituents
	Grain Size, Plasticity, and Soil	Natural Soil Deposits
	Soil Volume Relationships	Soil Index Properties and Classification
	Permeability and Capillarity	Stress Analysis and Engineering Properties
	Stresses in a Soil Mass	New Technology
	Consolidation	The Contract and Contract Documents
	Shear Strengths of Soils	Soil Testing
	Subsurface Exploration	Geotechnical Laboratory
	Lateral Earth Pressure	Soils Report
	Shallow Foundations	Interpretation of Soils Reports
	Deep Foundations	Embankment Construction and Control –Soil Control - Embankment, Control and Dewatering
	Retaining Walls	Foundations
	Slope Stability	Excavations and Excavation Supports/Dewatering
	Compaction	Contracting and Soils

4 CONCLUSIONS

If non-engineers have a good understanding of science and engineering concepts, they can better interact with scientists and engineers in the workforce and make informed decisions when it comes to engineering solutions. This paper compared the performance of engineering and non-engineering students in the introduction to geotechnical engineering and geotechnical applications course over four semesters. A deep examination reveals a significant variation in non-engineering students' grades depending on the way the course was taught. Non-engineering students performed better when the course was offered from a non-engineering perspective, catering to students' diverse backgrounds, rather than focusing on a quantitative engineering perspective. The results of this study highlight the need to develop clear and consistent teaching methods and techniques to ensure non-engineering students gain adequate engineering literacy. Although this paper highlights the effect of an important factor on the performance of non-engineering students in engineering courses, this preliminary study has limitations that need to be addressed in a larger research effort focusing on the topic: the sample size used in this study is limited to 381 students; the study investigates student performance in two specific courses and within one university; and the paper studies one specific factor out of several that can impact student performance. The preliminary findings of this study are currently being strengthened improved by investigating a larger sample of students and courses, and also considering including additional factors that affect the performance of non-engineering students in engineering courses.

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