Undergraduate Geotechnical Engineering Education of the 21st Century

Xenia Wirth [1], Ning-Jun Jiang [2]*, Talia da Silva [3], Gabriele Della Vecchia [4], Jeffrey Evans [5], Enrique Romero [6], Shobha K. Bhatia [7]

Introduction

Societies are facing more emerging challenges in the 21st century than ever before. The economic and social needs of deteriorating environments, depleted energy resources, and intensified natural disasters call upon geotechnical practitioners to respond to complex problems outside the traditional geotechnical boundaries in a knowledge-based and multi-disciplinary framework (Soga and Jefferis 2008). Geotechnical engineers are also expected to work across nations, cultural boundaries and social contexts, as well as to communicate effectively with all sectors of society (Galloway 2007). However, many current practices of geotechnical engineering are still empirical-based and constrained by traditional boundaries. Geotechnical professionals are often perceived as "unsophisticated, awkward in public, poor communicators, and without outside interests" (Marcuson et al. 1991). Unfortunately, the current geotechnical education curriculum does not provide the foundation necessary to ensure the engineer's success in the 21st century.

[1] PhD candidate, Department of Civil and Environmental Engineering, Georgia Institute of Technology, USA. Email: xwirth@gatech.edu
[2] Postdoctoral researcher, Department of Engineering, University of Cambridge, UK. (* corresponding author) Email: jiangningjun@gmail.com; nj263@cam.ac.uk, PH: +44 (0) 1223 766683
[3] PhD candidate, Schofield Centre, University of Cambridge, UK. Email: tsd30@cam.ac.uk
[4] Associate Professor, Department of Civil and Environmental Engineering, Politecnico di Milano, Italy. Email: gabriele.dellavecchia@polimi.it
[5] Professor, Department of Civil and Environmental Engineering, Bucknell University, USA. Email: evans@bucknell.edu
[6] Director of Research, Department of Civil and Environmental Engineering, Universitat Politècnica de Catalunya, Spain. Email: enrique.romero-morales@upc.edu
[7] Professor, Department of Civil and Environmental Engineering, Syracuse University, USA. Email: skbhatia@syr.edu

Therefore, substantial changes must be made through review and reform of the contemporary engineering curriculum. Encouraging multi-disciplinarity and fostering transferable skills must constitute core components of the overall geotechnical education.

The Accreditation Board for Engineering and Technology, Inc. (ABET) expects general student outcomes for future undergraduates in engineering to include not only a thorough knowledge of the subject materials, but also more transferable skills, such as: “an ability to communicate effectively,” “…understand the impact of engineering solutions in a global, economic, environmental, and social context,” and “a knowledge of contemporary issues.” (ABET 2014). The importance of these skills is recognized not only in the United States, but also in many other countries worldwide. This paper proposes an undergraduate geotechnical curriculum which attempts to encompass not only the technical criteria but also the transferable skills needed for geo-engineers.

The Bloom’s Taxonomy of Learning (Bloom et al. 1956) is an effective benchmark to measure levels of student learning (Dewoolkar et al. 2009). The Bloom’s Taxonomy of Learning consists of six levels in the cognitive domain of a student’s understanding of topics/concepts. These six levels, from the lowest to the highest, are ‘Knowledge’, ‘Comprehension’, ‘Application’, ‘Analysis’, ‘Synthesis’, and ‘Evaluation’ (Bloom et al. 1956). Anderson et al. (2013) revised the Bloom’s Taxonomy of Learning and updated the six levels, which are ‘Remember’, ‘Understand’, ‘Apply’, ‘Analyze’, ‘Evaluate’, and ‘Create’. The revision addresses both the ‘knowledge’ and ‘cognitive process’ dimensions and thus assists instructors with developing curricula and evaluating student outcomes. It has been further suggested that achievement within the cognitive domain alone is insufficient and that student achievement within the affective domain is needed, as the affective domain addresses the internalization of values and is an important complement beyond the cognitive domain (Lynch et. al. 2009).

The American Society of Civil Engineers (ASCE) has adopted Bloom's Taxonomy in its 2008 body of knowledge (BOK) for students planning to become professional civil engineers because it is familiar, well-documented in the engineering community, and has readily implementable outcome statements (ASCE 2008). ASCE Levels of Achievement Subcommittee recognized that Bloom's Taxonomy provides an appropriate framework for the articulation of BOK outcomes and related levels of achievement (ASCE 2008). The revised geotechnical curriculum should enable students to achieve a more comprehensive understanding, particularly at the 'Analyze', 'Evaluate' and 'Create' levels, based on Bloom's Taxonomy.

This paper has evolved from the International Workshop on Education of Future Geotechnical Engineers in Response to Emerging Multi-scale Soil-Environment Problems held on 5-6 September 2014 at the University of Cambridge, UK. Perspectives of full professors, middle-career faculty and PhD students are incorporated into a revised undergraduate geotechnical curriculum as discussed in detail in this paper.

Prerequisites

The requirements for a civil engineering undergraduate degree vary widely among geographic regions. More specifically, top-ranked programs in Europe, Asia and the Americas have different numbers of required credit hours, general education courses, and types of classes offered for the same degree (Zhou et. al. 2014; AIB UGS 2012). Therefore, it is difficult to propose generic curriculum requirements that would be acceptable for all systems (Russell and Stouffer 2005). That said, the following prerequisites are proposed to prepare students for the introductory geotechnical course and other technical electives, recognizing the fact that the following list may have too many or too few classes to be accepted at every university (**Table 1**).

Italicized in **Table 1** are the proposed prerequisites (‘Introduction to Civil Engineering’ and ‘Engineering Geology’), which will provide a more encompassing breadth of knowledge to first and second year civil engineering students. The ‘Introduction to Civil Engineering’ seminar course bridges a gap in the curriculum between first and second year students, who are just being introduced to engineering as a mathematical and scientific concept, and the third and fourth year students taking electives from each specific field (transportation, structures, geotechnical engineering, etc.). This course would be a 1-hour credit seminar course which introduces the various disciplines of civil engineering, where faculty, professionals, or graduate students from each discipline give presentations on suitable case-studies or research topics. Sustainability would also be addressed because it has become a crucial concept now in ABET program criteria for civil engineering programs, and is particularly important in civil engineering where large-scale projects demand a large quantity of material and energy that have significant social and environmental impacts (Seagren and Davis 2011). Though some universities, such as Georgia Institute of Technology and Syracuse University, incorporate a sustainability course in the undergraduate civil engineering curriculum, most universities have no such course, and students move directly from introductory engineering concepts (math, science, deformable bodies) to courses in specific disciplines (structural design, geotechnical engineering, transportation design) without understanding the field as a whole. A seminar course would be an appropriate way to transition without the burden of a complete extra course on the curriculum.

‘Engineering Geology’ is a subject essential to the undergraduate civil engineering curriculum. This class, though most suited for students interested in geotechnical engineering, is an important part of site investigation and characterization, which is applicable to all fields of civil engineering. A geology course would provide an introductory understanding of the formation of soil – its composition and nature, as well as properties of minerals and their variability. One difficulty lies in deciding what specifically to teach an engineer about geology. Topics recommended by Cawsey and Francis (1970) are divided into five categories: pure geology, site investigation, geological aspects of soil mechanics, rock mechanics, and hydrogeology. Pure geology for civil engineering focuses mostly on weathering, soil formation, and structural geology. Site investigation covers not only boreholes and other typical site analysis procedures but also includes the reading of geological maps and knowing where to find geologic data. Slope stability and origin of soils is addressed in the third category, and tunneling, strength, and fracturing of rocks in the fourth. Hydrogeology covers another very important aspect of civil engineering, the movement of water. Although the modules and lesson plans are left to the individual instructor, the core concepts presented above are an excellent foundation for an 'Engineering Geology' course. Otherwise, students, lack some fundamental understanding of one of the most basic of civil engineering materials, i.e. soil.

Introductory Geotechnical Engineering Course

Overview

A typical academic year in universities is divided into several (e.g., two, three, four or more) teaching semesters, terms, or quarters. The introductory geotechnical course varies from university to university, though it often includes a laboratory section to gain practical experience in soil testing and to reinforce concepts taught in the lecture portion of the course. **Table 2** reviews the curriculum and class format for the introductory geotechnical course for engineering undergraduates at universities in Europe and USA. The variations shown in **Table 2** are reflective of the variations common when the course is taught at different universities.

The classroom format for the proposed introductory geotechnical engineering course, "Geotechnical Engineering I" has the following generic criteria:

- Length: 40-hour class completed in one semester
- Target group: Third-year undergraduate
- Class sizes: 40-100 students (can be less for laboratory sections)
- Laboratory section: 2-3 hours per week

In order to generate interest and allow the students to develop a more detailed understanding, the course should include some demonstrations and/or site visits. These active learning activities encourage student involvement and reinforce engineering concepts in "real-life" applications (Donohue 2014). There should be at least one site visit per semester and at least two tabletop demonstrations in addition to weekly lab instruction. Suggested modules and demonstrations appropriate for this class will be discussed in a following section.

Fundamental content and approach

The proposed geotechnical introductory course is the first civil engineering course focused solely on geotechnical engineering. Therefore, it includes many of the same topics of most established introductory soil mechanics classes, as shown in **Table 3**.

The lecture content should include the core theoretical knowledge of soil mechanics, but should also include an introduction to geotechnical structures and case studies of both failures in design and notable accomplishments in geotechnical engineering. Foundation design and in-situ testing are sometimes reserved for the second undergraduate elective geotechnical course or for graduate study, but as this may be the only geotechnical introductory course that some students take in their entire university study, we feel it is important to at least introduce the practical applications of geotechnical engineering in this course. The more advanced, more detailed topics in in-situ testing and foundation design are reserved for the graduate level, however.

Although some students enjoy learning theoretical derivations for soil mechanics and often they can be helpful, the authors propose to limit time spent on soil shear strength or consolidation analytical solutions in favor of more practical applications of geotechnical engineering. It would be better to use this time to introduce students to geotechnical structures and in-situ testing that they will frequently observe in their professional engineering careers. The course would still include an introduction to consolidation, seepage, and soil shear strength, but the heavy derivations would be reserved for the graduate level or other undergraduate electives, if there are enough geotechnical engineering courses offered at the undergraduate level. In addition to the fundamental knowledge in soil mechanics and geotechnical engineering, the revised introductory course should also embrace the modern developments within the geotechnical field. For example, thermal, hydraulic, electrical, biological, and mechanical processes all play a role in soil particle/fluid interactions, as well as in multi-scale phenomena and multi-physics coupling in porous media. The 21st century geotechnical engineer should be aware that these processes may influence bulk properties and soil behavior. The course at undergraduate level should therefore include notions of mechanics of unsaturated soils (porous material with two interstitial fluids), as a way to introduce other hydro-mechanical coupled process besides the theory of consolidation. Moreover, advancements in technology can be excellent and thought-provoking visual aids for presenting particle features of soil behaviour and soil particle interactions. For example, DEM and FEM simulations could be used to show how soil particles respond to dynamic earthquake loading or how a slope responds under heavy construction loading or heavy rainfall conditions, and electromagnetic geophysics can exemplify how a subsurface profile can be extremely heterogeneous (Abbo et. al. 2012).

Undergraduate Geotechnical Engineering Curriculum

Overview

The proposed undergraduate geotechnical curriculum would have four core courses and one seminar course (**Table 4**) essential to geotechnical engineering including: Introduction to Civil Engineering (seminar), Engineering Geology, Geotechnical Engineering I (Introductory Geotechnical Course), Geotechnical Engineering II, and Geotechnical Engineering III. The first three would be mandatory for all civil engineering students, and the last two are electives that students interested in a geotechnical engineering concentration could take. They could be offered annually or bi-annually depending on enrollments and faculty resources and would be primarily for third, fourth, and fifth-year students (if applicable). The last two electives could also be graduate-level geotechnical engineering courses at programs with limited undergraduate geotechnical engineering curriculums. Particularly at institutes with limited faculty or course offerings, students should be strongly encouraged to pursue a graduate-level education in geotechnical engineering before beginning a career in the field.

The Geotechnical Engineering III course provides a unique opportunity to tailor geotechnical engineering to specific issues in the geographic area. For example, in Puerto Rico, the undergraduate geotechnical curriculum includes a natural hazards course (Perdomo and Pando 2014). This area is highly susceptible to natural hazards such as hurricanes, extreme weather events, earthquakes, tsunamis and floods (Perdomo and Pando 2014). In programs with a heavier emphasis on environmental engineering, this course could be focused on environmental soil remediation and landfill design. In this way, Geotechnical Engineering III would be a specialized course for those students who have a continued interest in or plan on a career in geotechnical engineering.

Suggested modules and activities

One of the challenges faced by geotechnical engineering is rooted in the undergraduate student perspective. While high school students certainly see roads, bridges and buildings as part of daily living, they are unlikely to be exposed to soil mechanics or foundation engineering. Furthermore, in the minds of undergraduate students, geotechnical engineering is often viewed as one of the least glamorous of the civil engineering disciplines. Most students do not consider "playing with dirt" to be as influential as constructing the next highway system or skyscraper, and they do not understand how important the subsurface is in the successful performances of the highway system or skyscraper. Finally, many students (and engineers) are uncomfortable with uncertainty in engineering judgment and are more comfortable in other more prescribed civil engineering disciplines. Changing this perspective should be a priority in the undergraduate geotechnical curriculum.

Conventional "chalk and talk" style lectures can lead students to conclude learning about soil is boring. Lecture-style learning should be augmented with engaging classroom activities and demonstrations to encourage interest in geotechnical engineering (Abbo et. al. 2012). Interactive modules and other, non-lecture-based learning opportunities also break up the tedium of typical lectures. Active-learning activities are designed to promote critical thinking skills and provide a more detailed and visually-appealing understanding of the subject material. Group work improves student communication and teamwork skills (conflict resolution, project management and leadership), which are crucial skills for the engineering workforce (Pinho-Lopes et. al. 2011). By encouraging geotechnical engineering faculty to effectively use these types of activities, more students will be attracted to geotechnical engineering (Felder et al. 2000). They are also expected to have better academic performance (Freeman et al. 2014).

Demonstrations, modules, case studies and other activities have been used to improve the student learning experience (Dewoolkar et. al. 2009; Newson and Delatte 2011; Pinho-Lopes et. al. 2011). Some examples include: shake tables to show liquefaction of sandy soils, electrically-conductive paper to simulate water flow through soil, centrifuge modeling, and critical analysis of laboratory procedures for soil properties, among others (Dewoolkar et. al. 2009). Laboratory-scale centrifuge modeling, in particular, is a great advantage in the classroom for displaying dynamic soil behavior. This technique has been used with much success in simulating a variety of geotechnical situations, including pipe uplifting with cohesive backfills, seismic events, wave propagation through soils, foundation loading, and retaining wall loading, among others (Cabrera and Thorel 2014; Craig 2014; Jacobsz et al. 2014; Springman 2014; Wilson and Allmond 2014). It worth mentioning that Elton (2001) has provided a fascinating collection of simple, inexpensive, but intriguing experiments focusing on the principles of soil mechanics. These models may be directly referred to by instructors. In addition, working groups orally presenting different topics assigned by the professor are also possible ways to complement the learning experience (leaning tower of Pisa and stabilization methods adopted, failure of Carsington dam, the Vaiont landslide, geotechnical aspects of the construction of the Channel Tunnel, artificial ground freezing, …).

Potential challenges

The authors understand that replacing a traditional lecture format for more work-intensive, interactive sessions and including a larger breadth of geotechnical topics and classes in an undergraduate geotechnical engineering curriculum is a significant undertaking. However, these challenges can be addressed individually and slowly, if needed, as long as progress is made in teaching students as effectively as possible. The engineering world is changing, and education must adapt to not only new criteria requirements, but new responsibilities for the engineers of the 21st century.

The proposed curriculum cannot be easily adapted at every university. Universities which have limited flexibility in course offerings, fewer credits needed for graduation, or government-or-university-imposed additional requirements may have the most difficulty in implementing a redesigned program (Estes et. al. 2015; Perdomo and Pando 2014). Issues are anticipated in a university with small enrollments or few faculty members, and therefore, few students interested in a geotechnical concentration. Regardless, all civil engineering students should still have the benefit of a geotechnical engineering education from the "Engineering Geology" and "Introductory Geotechnical Engineering" courses, even if these classes are the only exposure they receive before graduating.

A question emerges when considering how to implement the changes proposed above as part of the "Introductory Geotechnical Engineering" course. How much can both traditional and new concepts realistically fit into a curriculum? Most courses are approximately 40 hours of teaching, yet classroom demonstrations, site visits, and exams takes time from learning core concepts. These activities are instrumental in providing the 21st century student with the skills needed to be a professional engineer, but the core concepts of geotechnical engineering must also be taught. Interdepartmental collaboration could assist faculty in introducing geotechnical engineering to students earlier in their study and by doing so, create space in the introductory geotechnical engineering course. For example, an introduction to fluid flow through porous media could be presented in an undergraduate fluid mechanics course, and a discussion on Mohr's circle in a Mechanics of Materials course could incorporate soil shear strength as an example. The civil engineering materials course could have a subsection on soil classification. Moving more complex scenarios in soil mechanics to the graduate level is another way of relieving pressure on the introductory geotechnical course. Students should be encouraged to continue their education in geotechnical engineering on the graduate level, particularly if they want to pursue a career in geotechnical engineering. The graduate education will give them the extra breadth and depth of material that cannot be included at the undergraduate level. Incorporating new concepts, modules, and new courses is also more work for the instructors. Lesson plans that have been firmly established must be altered, and energy and time must be spent in analyzing the effectiveness of new teaching methods. Students also tend to resist a more integrated lecture format because it requires more of their time, and group work can be more demanding than a typical homework assignment (Dewoolkar et. al. 2009; Newson and Delatte 2011).

Addressing these changes will take significant effort, but they are possible. Defining clear learning objectives at the beginning of the semester and following them closely helps both students and instructors (Fiegel 2013; Newson and Delatte 2011). Tracking student progress and survey responses has provided insight for other instructors who made similar improvements as those proposed above (Dewoolkar et. al. 2009; Perdomo and Pando 2014). If there are multiple instructors for a course, teachers can distribute the workload to ease the burden. Some modules used volunteer graduate students to help, particularly for showing undergraduates how to use field and lab equipment (Dewoolkar et. al. 2009). Although the process seems daunting, the professional educator must adapt not only to the advances in civil engineering but also to the necessary accompanying changes that must be made in the engineering education system.

Measuring Course Success

The last essential portion of implementing changes to the undergraduate engineering education system is measuring course success. Student surveys have been used by many researchers as a gauge of success. If students have difficulties understanding and implementing the new concepts, changes will not be effective (Dewoolkar et. al. 2009; Fiegel 2013; Perdomo and Pando 2014; Pinho-Lopes et. al. 2011). Students' perspectives and experiences are evaluated with subjective responses such as "strongly agree", "strongly disagree" or "neutral". These surveys are particularly important when implementing modules that require group work, to identify the most effective way to encourage student collaboration. Often, each opinion is assigned a numerical rank (e.g. 1-4) which then is statistically analyzed (Pinho-Lopes et. al. 2011). Peer-evaluated responses, in which students rate one another's group contributions, are another method of ensuring equal collaboration (Newson and Delatte 2011). Instructors adjust individual grades based on the responses of the group members. The teacher's perspective is also necessary when deciding if a curriculum change should be implemented. Significant curriculum changes such as interactive modules and critical reports, among others, require the teacher to take on a higher workload, both in grading these assignments and taking time to help students who are struggling (Dewoolkar et. al. 2009; Newson and Delatte 2011). A professor must have the time and energy to make the necessary changes in order for them to be effective in the classroom. Those who would advocate for new modules and activities must have the commitment of the professors who will be teaching those classes.

Improvements in student performance have been successfully measured by comparing examination and quizzes grades to previous semesters. Teachers must share data to understand if better concept retention is attributable to the introduction of new teaching styles and modules. Graded exams and quizzes provide the numerical data to statistically track improvement (Dewoolkar et. al. 2009; Fiegel 2013). Measuring the percentage of students to correctly answer a particular type of question is one method of doing so. Fiegel (2013) encouraged the use of daily quizzes to monitor student learning and retention over the course of the semester. The quizzes were short, 5 minute, 1-2 question assignments given at the end of every lecture, to test on concepts presented during the class period. They were simple problems that were easy to grade, yet they provided some "real-time" measure of student comprehension which allowed the instructor to adjust lecture concepts accordingly.

Although the effectiveness of interactive modules and activities were difficult to measure numerically, the students seemed to respond positively to the new activities at University of Vermont, citing that they helped the students better understand the engineering concepts (Dewoolkar et. al. 2009). Students at other universities had similar positive feedback when case studies were introduced to the curriculum (Abbo et. al. 2012; Newson and Delatte 2011). More recently, Freeman et al. (2014) analyzed 225 case studies that provided data on examination scores or failure rates. Student performance in undergraduate science, technology, engineering, and mathematics (STEM) courses was compared between traditional lecturing and active learning. It is reported that average examination scores are improved by around 6% in active learning than traditional lecturing. Students in classes with actively learning are 1/3 less likely to fail than in traditional lecturing classes (Freeman et al. 2014).

Conclusion

A critical approach needs to be taken to evaluate the effectiveness of the current undergraduate geotechnical engineering curriculum. New criteria are being introduced on the national and international levels to create a 21st century engineer that has a strong background in core concepts and professional skills to compete in a global, economic, environmental, and social engineering context (Estes et. al. 2015; ASCE 2008). Both curriculum and classroom changes are necessary to update the undergraduate engineering education. New introductory courses provide a more thorough introduction to civil engineering and sustainability; new teaching styles and modules incorporate technological advances, encourage critical thinking and other professional skills, and promote student interest in geotechnical engineering. The geotechnical engineering field is increasing in complexity, and the undergraduate engineering curriculum must embrace the challenges of educating the 21st century engineer.

Acknowledgements

The authors would like to thank the National Science Foundation (NSF) for providing the funding to organize the International Workshop on Education of Future Geotechnical Engineers in Response to Emerging Multi-scale Soil-Environment Problems held on 5-6 September 2014 at the University of Cambridge, UK. The authors would also like to thank the American Society of Civil Engineers (ASCE) for providing the educational journal to publish this article. Without your support, this work would not have been possible. The authors also thank Prof. Guido Musso, Dr. Federico Pisanò and Dr. Anne-Catherine Dieudonne for providing information about geotechnical courses in EPFL, University of Liege, Politecnico di Torino, and Delft University of Technology.

References

Abbo, A. J., Fityus, S. G., and Mackenzie, S. (2012). "Dunmore Bridge case study: an introduction to geotechnical engineering via finite element analysis." *Shaking the Foundations of Geo-engineering Education*, Taylor & Francis Group, London. 171-176.

ABET (2014). *Criteria for accrediting engineering programs*. Accreditation Board for Engineering and Technology, Inc., Maryland.

AIB UGS (2012). *Model scheme of instruction and syllabi for UG engineering degree programmes (civil engineering).* All India Board for UG Studies in Engineering and Technology. 1-15.

ASCE (2008). *Civil engineering body of knowledge for the 21st century, 2nd edition.* American Society of Civil Engineers, Virginia.

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

Bloom, B. S., Englehart, M. D., Furst, E. J., Hill, W. H., and Krathwohl, D. (1956). *Taxonomy of educational objectives: The classification of educational goals: Handbook I: Cognitive domain*, David McKay, New York.

Cabrera, M., and Thorel, L. (2014). "Dynamic actuator for soil-structure interaction physical modelling in centrifuge." Physical Modelling in Geotechnics - Proceedings of the 8th International Conference on Physical Modelling in Geotechnics 2014, ICPMG 2014, 1, 215–220.

Cawsey, D. C., and Francis, C. M. G. (1970). "Geological engineering for undergraduate civil engineers." *Q. Jl. Engng Geol.*, 3, 253-258.

Craig, W. H. (2014). "Simulating cohesive backfills in centrifuge models of subsea pipelines." Physical Modelling in Geotechnics - Proceedings of the 8th International Conference on Physical Modelling in Geotechnics 2014, ICPMG 2014, 1, 459–464.

Dewoolkar, M.M., George, L., Hayden, N.J., and Neumann, M. (2009). "Hands-on undergraduate geotechnical engineering modules in the context of effective learning pedagogies, ABET outcomes, and our curricular reform." *J. Prof. Issues Eng. Educ. Pract.*, 135(4), 161-175.

Donohue, S. (2014). "Supporting active learning in an undergraduate geotechnical engineering course using group-based audience response systems quizzes." *Eur. J. Eng. Educ.*, 39(1), 45-54.

Elton, D. J. (2001). *Soils Magic (Geotechnical Special Publication 114),* American Society of Civil Engineers, Reston, Virginia.

Estes A. C., Lenox, T. A., and Anderson, R. O. (2015). "New civil engineering program criteria: the rest of the story." *American Society for Engineering Education*, 26.1185.1-31.

Felder, R. M., Woods, D. R., Stice, J. E., and Rugarcia, A. (2000). "The future of engineering education II. Teaching methods that work." Chem. Eng. Educ., 34(1), 26-39.

Fiegel, G.L. (2013). "Incorporating learning outcomes into an introductory geotechnical engineering course." *Eur. J. Educ. Eng.*, 38(3), 238-253.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., and Wenderoth, M. P. (2014). "Active learning increases student performance in science, engineering, and mathematics." *Proc. Natl. Acad. Sci. U.S.A.*, 111(23), 8410-8415.

Galloway, P. (2007). Engineering Education Reform. *The 21st-Century Engineer*, pp. 87-98. doi: 10.1061/9780784409367.ch07

Jacobsz, S. W., Kearsley, E. P., and Kock, J. H. L. (2014). "The geotechnical centrifuge facility at the University of Pretoria." Physical Modelling in Geotechnics - Proceedings of the 8th International Conference on Physical Modelling in Geotechnics 2014, ICPMG 2014, 1, 169–174.

Lynch, D. R., Russell, J. S., Evans, J. C. and Sutterer, K. G. (2008), "Beyond the Cognitive: The Affective Domain, Values and Achievement of the Vision," *ASCE J. of Professional Issues in Engineering Education and Practice*, 135(1), pp.47-56.

Marcuson, W., III, Dobry, R., Nelson, J., Woods, R., and Youd, T. (1991). "Issues in Geotechnical Engineering Education." *J. Prof. Issues Eng. Educ. Pract.*, 117(1), 1–9.

Newson, T.A., and Delatte, N.J. (2011). "Case methods in civil engineering teaching." *Canadian Journal of Civil Engineering*, 38, 106-1030.

Perdomo, J.L., and Pando, M.A. (2014). "Using information technology to incorporate natural hazards and mitigation strategies in the civil engineering curriculum." *J. Prof. Issues Eng. Educ. Pract.*, 140(1): 04013004.

Pinho-Lopes, M., Macedo, J., and Bonito, F. (2011). "Cooperative learning in a soil mechanics course at undergraduate level." *Eur. J. Eng. Educ.*, 36(2), 119-135.

Russell, J. and Stouffer, W. (2005). "Survey of the national civil engineering curriculum." *J. Prof. Issues Eng. Educ. Pract.*, 131(2), 118-128.

Seagren, E.A., and Davis, A.P. (2011). "Integrating fundament science and engineering concepts into a civil engineering sustainability course." *J. Prof. Issues Eng. Educ. Pract.*, 137(4), 183-188.

Soga, K., and Jefferis, S. A. (2008). “Contributions to Géotechnique 1948–2008: Soil science and interdisciplinary aspects of geotechnical engineering.” *Géotechnique*, 58(5), 441-448.

Springman, S. M. (2014). “Lessons learnt from centrifuge modelling of sand compaction piles and implications for design.” Physical Modelling in Geotechnics - Proceedings of the 8th International Conference on Physical Modelling in Geotechnics 2014, ICPMG 2014, 1, 21-43.

Wilson, D. W., and Allmond, J. D. (2014). “Advancing geotechnical earthquake engineering knowledge through centrifuge modeling.” Physical Modelling in Geotechnics - Proceedings of the 8th International Conference on Physical Modelling in Geotechnics 2014, ICPMG 2014, 1, 125–137.

Zhou, Y., Zhang, J., Li, L., Liao, S., and Fang, Z. (2014). “Comparison analysis of civil engineering undergraduate curriculum among universities in China, US, and Europe.” *Appl. Mech. Mater.*, 638, 2402-2408.

Table 1. Proposed prerequisite courses for a civil engineering undergraduate student, to be completed within the first three years of study.

General Subject	Courses
Math	• Calculus (single variable differentiation and integration, series, multi-variable) • Linear Algebra • Differential Equations (PDE and ODE)
Sciences	• General Physics (dynamics and electromagnetics) • General Chemistry • Biology or Earth Sciences
General Engineering	• Statics • Deformable Bodies (Continuum Mechanics) • Dynamics • Material Sciences • Thermodynamics
General Civil Engineering	• Fluid Mechanics • Strength of Materials • *Introduction to Civil Engineering (Seminar course)* • *Engineering Geology*

Table 2. Review of curriculum and format for the introductory geotechnical engineering course for the engineering undergraduate in USA and European universities.

University	Topics Included	Lecture Format
Bucknell University, USA	• Origin, composition, structure, and properties of soils • Identification, classification, strength, permeability, and compressibility characteristics • Introduction to foundation engineering • Laboratory determination of soil properties	Lecture hours: 42 Laboratory hours: 28 Semester length: 14 weeks of instruction plus final exam week Credits: 4
Politecnico di Milano, Italy	• Soil origin, classification and physico-chemical properties • Field equations for porous media • Seepage • Consolidation • Mechanical behaviour of soils and constitutive modeling • Earth pressure and retaining structures • Introduction to slope stability and excavations • Bearing capacity of shallow foundations • Settlement evaluation	Lecture hours: 96 Laboratory hours: 0 Exercise hours [1]: 48 Semester length: 12 weeks of instruction Credits: 10
Georgia Institute of Technology, USA	• Soil characterization and classification • Compaction and soil improvement • Stresses in soils • Shear strength • Fluid flow through porous media • Settlement analyses • Earth retaining structures	Lecture hours: 48 Laboratory hours: 48 Semester length: 16 weeks of instruction plus final exam week Credits: 4
Syracuse University, USA	• Nature and composition of soils • Formation and classification of natural soils and man-made construction materials • Compaction, permeability and seepage • Consolidation and settlement • Shear behavior and strength	Lecture hours: 44 Laboratory hours: 40 Semester length: 16 weeks of instruction plus one week of final exams Credits: 4
University of Cambridge,	• Basic definitions of soil constituents, and their packing,	Lecture hours: 16 Small group supervision: 4

UK	soils in nature, and the principle of effective stress • Compaction, steady state seepage, compressibility and stiffness • Consolidation, transient flow, and oedometer test • The shear strength of soils • Limit equilibrium of geotechnical structures, shallow foundation design, and retaining structures	Laboratory hours: 1 session Semester length: 8 weeks of instruction
University of Liege, Belgium	• Soil mechanics (introduction, granular media, physical properties, classification, water in soils, seepage, soil - water interaction, mechanical properties, in situ stress state) • Slope stability • Retaining structures (gravity walls, sheet piles) • Shallow foundations and deep foundations • Roads: design and structural behaviour.	Lecture hours: 26 Practice hour [2]: 26 Laboratory hours: 2 Field work: half day Credits: 5
École Polytechnique Fédérale de Lausanne (EPFL), Switzerland	• Experimental methods • Effective stress principle • Introduction to the non-linear behaviour of soils • Seepage and 1D consolidation • Elastic solutions • Limit analysis and applications, retaining structures, dams, slope stability • Numerical methods (FEM, FDM)	Lecture hours: 42 Exercise hours [1]: 28 Laboratory hours: 14 Semester length: 14 weeks of instruction Credits: 5
Politecnico di Torino, Italy	• Description and classification of soils • Mechanical behaviour of soils: effective stress principle, oedometer test, triaxial test • Seepage • Consolidation • Limit analysis • Earth thrust • Bearing capacity of shallow foundations	Lecture hours: 80 Practice hour [2]: 20 Laboratory hours: 0 Credits: 10
Delft	• Soil characteristics	Lecture hours: 36

University of Technology, the Netherlands	• Groundwater: pore pressure and effective stress; • Darcy's law, permeability and groundwater flow • Elastic solutions • Consolidation, drained and undrained behaviour • Shear strength of soils • Site investigation and soil sampling • Retaining structures • Foundations • Slope stability with limit equilibrium methods	Practice hour [2]: 12 Laboratory hours: 0 Credits: 5
Universitat Politècnica de Catalunya, Spain	• Soil characterization • Flow: solving flow problems, flow in unsaturated soils. Effective stress • Experimental behavior: basics of mechanics of continua, stress paths. Behavior of clays and sands • Mechanical behavior: Cam-clay model, shear strength, introduction to unsaturated soils • Failure analysis: plastic collapse theorems, slope stability • Consolidation: one-dimensional theory and with radial flow	Lecture hours: 62 Practice hour [2]: 18 Laboratory hours: 9 Guided activities: 4 (group coursework) Semester length: 15 weeks of instruction Credits: 9

[1] Exercise hour: a practice session, during which some problems or exercises are proposed by a younger collaborator of the professor (e.g. a PhD student or a research associate...) and then the solution is shown, together with all the calculations.
[2] Practice hour: similar to exercise hour.

Table 3. Proposed content for the introductory geotechnical engineering course.

General Topics	Specific Content
Soil classification	• Soil heterogeneity and anisotropy • USCS and other classification systems • Physical properties (shape, size, color, porosity, plasticity, etc.) • Phase relationships • Clay mineralogy; clay-water electrolyte system
Water	• Hydraulic conductivity and Darcy's law • Seepage • Effective stress
Mechanical behavior	• Non-linearity of the stress-strain relationship • Oedometer and triaxial tests • Shear strength, Mohr's circle and friction angle • Drained and undrained stress response • Overconsolidation Ratio
Geo-structures	• Earth pressure and retaining walls • Embankments and dams (flow, filters, drains, rapid drawdown) • Shallow foundation design: settlement and bearing capacity
Hydro-mechanical coupling	• Consolidation
Others	• Compaction • Introduction to mechanics of unsaturated soils (flow, constitutive stresses, hydro-mechanical behaviour) • Case studies • In-situ testing (introduction)

Table 4. The proposed undergraduate geotechnical engineering curriculum, to best prepare a geotechnical engineering student of the 21st century

Course Name	Student Year	Course Content
Introduction to Civil Engineering (Seminar)	1st, 2nd year (required)	• Sustainable design • Disciplines within civil engineering (transportation engineering, structural engineering, geotechnical engineering, hydrological engineering, environmental engineering)
Engineering Geology	1st, 2nd year (required)	• Pure geology • Site investigation • Geological aspects of soil mechanics • Rock mechanics • Hydrogeology
Geotechnical Engineering I	3rd year (required)	• Soil classification • Fluid flow through soils (flow through partially saturated soils) • Mechanical behavior (oedometer and triaxial tests) • Geo-structures: retaining walls, embankments, dams, shallow foundations • Hydro-mechanical coupling (basic introduction to consolidation) • Compaction • Shallow foundation design • Introduction to in-situ testing
Geotechnical Engineering II	4th year (elective)	• Derivation and numerical solutions of seepage and consolidation equations • Critical state soil mechanics (CSSM) • Comprehensive shallow and deep foundations: bearing capacity and settlement calculations for fine and coarse grained soils • Comprehensive in-situ testing and site analysis • Drilling and sampling • FEM/DEM demonstrations • Mechanics of unsaturated soils (introduction to porous media with two interstitial fluids: constitutive stresses, coupled hydro-mechanical behaviour)
Geotechnical Engineering III	4th year (elective)	• Environmental geotechnics • Energy geotechnics (thermal and geochemical coupled processes: energy geo-structures, energy geo-storage)

		• Detailed laboratory testing procedures (introduction for testing partially saturated soils and multi-scale testing) • Slope stability (embankments, cuts and natural slopes) • Ground improvement • Seismic design of geotechnical structures • Specific geographic applications