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# Introduction of Cooperative and Competition-Driven Learning in Geotechnical Engineering Education

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ABSTRACT: Geotechnical engineering education relies heavily on traditional methods of teaching where theory is presented first, followed by applications. The current paper presents an alternative way of teaching Soil Mechanics to junior level students, incorporating cooperative learning and competition. Students worked in groups to solve in-class and homework assignments while competing with each other on completing the assignments, with bonus points accumulated for correct answers. The goal of the suggested teaching approach was to enhance the ability of the students to work collaboratively in groups and learn through teaching and being taught by their classmates, while playing a game. To evaluate the efficiency of the module, students were asked to respond to a survey regarding their experience with both traditional and cooperative learning styles. The results showed that students consistently prefer group over individual assignments. Moreover, students responded that group problem-solving enhanced and deepened their understanding of theories presented by the instructor. The role of the competition aspect of the approach was ambivalent, as perceived by students. The survey results suggest that it made problem-solving more engaging and enjoyable, but it was also a stressful experience for some students.

*Keywords: Cooperative learning, Competition, Soil Mechanics, Education*

## 1 Introduction

In the majority of universities around the world, engineering courses are still taught the same way they were taught decades ago. This classic method of teaching is mostly deductive, where the theory is presented first by the instructors, followed by example problems, the latter of which may in some cases be led by teaching-assistants during recitation hours. Also, sometimes students are given homework problems to solve individually in order to practice what they learnt in class. Students learn to follow specific procedures for solving problems, by mimicking the steps the instructors follow in the class. That way students tend to memorize methods for the exams (short-term) without truly incorporating this knowledge into their belief system (long-term) (Prince and Felder, 2006).

Alternative methods of teaching include inductive approaches, where students have a more active role in their learning. Numerous studies have highlighted the benefits of inductive methods in teaching engineering courses. According to Prince and Felder (2006), inductive methods include; a) inquiry-learning, b) discovery-learning, c) problem and project-based learning (PBL), d) case-based teaching, and e) just-in-time learning. The most traditional method of inductive teaching is inquiry-learning, where the instructor asks questions or poses problems and the students need to apply the methods they learnt, in order to find the solution (Bateman, 1990; Prince, 2004; Lee, 2012). Similarly, the discovery-learning approach involves questions or problems where students have to find the solution but without any directions or guidance by the instructor. The students work in a self-directed way and “discover” the desired factual and conceptual knowledge in the process, while the instructor simply provides feedback (Leonard, 1988; Westbrook and Rogers, 1994).

Problem-based and project-based learning (PBL) methods are similar to discovery-learning in the sense that students have to solve a problem while the instructor does not provide guidance but has the role of facilitator. However, in this case, students have to solve a real-world open-ended problem, and work in teams to develop a viable solution (Dahlgren, 2003; Weiss, 2003; De Graaf and Kolmos, 2003; Jensen et al., 2003). Case-based teaching, frequently seen in courses offered by business schools, is similar to problem-based learning, however the given problem/case, real or hypothetical, is more well-structured and with more details than the problem-based learning (Fitzgerald, 1995). Finally, the ‘just-in-time teaching’ (JITT) method combines web-based technology and active learning methods (Modesitt et al., 1999). It involves questions assigned to the students to answer online a few hours before the class, while the instructor reads through the answers and adjusts the lecture accordingly (just-in-time).

All inductive methods mentioned above rely on a fundamental principle; constructivism. Based on constructivism, individuals filter new information through mental structures that incorporate their prior knowledge and beliefs, and actively construct their own reality, independently of whether or not there is one objective reality (Biggs, 1996). When constructivism is applied in teaching, students construct knowledge for themselves, thus they have an absolute active role in the learning. To make constructivism effective, instructors should a) present new material making the connection with real-world applications and other areas of knowledge, b) encourage students to work inside their zone of proximal development, meaning the area between what they are capable of doing independently and in collaboration with more capable peers, c) require students to fill in gaps and extrapolate knowledge presented by instructors, and d) encourage students to work in groups.

Many educational studies and cognitive researches have shown that intellectual development, critical thinking and problem solving, essential skills to scientists and engineers, are promoted more efficiently through inductive than deductive teaching (Smith, 1996; Oliver-Hoyo et al., 2004; Oliver-Hoyo and Allen, 2005; Prince and Felder, 2006; 2007). However, although inductive teaching approaches can be more effective in helping students understand the concepts and retain information for longer, they don’t necessarily guarantee student engagement throughout the length of the course.

Instructors in engineering design courses often adopt problem-based and project-based methods for teaching design methods, with the climax being the capstone project, where students have to use the skills and knowledge gained throughout the curriculum to work as a team on a real design project. One of the geotechnical engineering courses that follows the same teaching style is ‘Foundation Design’ course which is offered usually in the senior (fourth) year of civil engineering undergraduate studies. However, courses that focus more on theory, such as ‘Soil Mechanics’, are usually taught following more deductive methods (i.e. instructor teaches theory and shows application examples). Homework problem sets are typically assigned at the end of lessons or topics, so that students practice what they learnt in class.

This paper suggests an alternative way of teaching Soil Mechanics to junior level (third year) students, based on the principles of constructivism. To enhance student engagement in the course, the proposed approach incorporates cooperative learning and competition in the form of a game. Students competed on completing and submitting assignments, with bonus points accumulated for correct answers. The goals of the suggested teaching approach were to: a) enhance the ability of the students to work collaboratively in groups, both in and out of class, b) create an atmosphere of achievement, as students not only learned to apply theories themselves, but also through helping and interacting with other team members c) enhance the efficacy of problem solving in understanding of theories through collaborative learning, and d) encourage learning and engagement by incorporating a competitive component to the exercises, thereby simulating a game environment.

## 2 Alternative method of teaching Soil Mechanics

### 2.1 Suggested Educational Module

In the proposed educational module, class starts with lectures on Soil Mechanics concepts in the traditional deductive way. The instructor presents the theory and shows basic conceptual examples of applications but without solving complex problems. That way, students do not have a reference when they are asked to solve a problem, thus their process of thinking is not guided, but they are left unrestricted to ‘construct’ their own solution (*constructivism*).

The class is divided into groups of 3 to 5 students (depending on the size of the class), with the goal of creating heterogeneous groups including a mix of strong and weak students. If applicable, it is also desirable to have group heterogeneity in terms of gender and race. Students are encouraged to collaborate with their group members to solve the in-classroom problems, as well as the homework assignments. Specific roles are not assigned to group members; students are unrestricted to choose whether they will all work on the assignments a) collaboratively, b) individually and then compare their solutions, or c) have distinctive roles (*e.g.*, one student is leading the solution, others follow, etc.).

The goal of having heterogeneous groups is to enhance student team-work spirit even when they are working with people they are not used to, or they do not necessarily feel comfortable with. Also, students learn better by explaining their thought process while solving problems. Thus, strong students learn the concepts by guiding the solution and teaching their peers, while weaker students learn from participating in the discussion. Hopefully, this procedure will also help reserved students to feel more comfortable to take the lead in solving the problem, as they will be talking among peers in a small group, thereby mitigating the fear of making a mistake.

After a Soil Mechanics concept is completed in the lectures, the instructor gives an application problem to the student to solve in the classroom. To keep the class on track, a time limit should be set. Students have to pay attention throughout the lectures and use their critical thinking in order to apply the theory for solving the problem. To increase student engagement and keep them entertained, the teams have to work on the solution and compete with each other on submitting their correct answers as fast as possible, for the chance of getting extra points. The first team to submit their answer correctly, gets 5 extra points on that specific week's assignment (for a grade out of 100). The instructor has to evaluate their answer in the class and decide on the winning team. The majority of the problems assigned in class and as group homework assignments are adopted, with some modification, from soil mechanics textbooks (*e.g.,* Coduto et al., 2011; Budhu, 2015; Das and Sobhan, 2018), see Example 1 in Appendix A.

After the period of time allowed for solving the problem is completed, the instructor presents to the class the winning team's solution, and, if applicable, alternative correct solutions suggested by the other teams. The instructor can monitor the progress of groups, interact with group members to encourage participation, and address questions in guiding groups in their collective efforts to solve the problem. Through these interactions, the instructor can directly evaluate, in near real-time, student progress, and can identify topics to address in more detail as the lesson progresses. The role of the instructor is flexible, as providing some guidance, without directly answering the question, can be encouraging and give some confidence to the students, in addition to building personal rapport.

The same logic is applied for the homework assignments, see Example 2 in Appendix A, where students have to work again with their assigned group members to solve problems correctly and submit them as quickly as possible within a certain timeframe, having extra points as a reward. The extra points may be different each time, depending on the length and difficulty of the assignment. The use of an online submission system is suggested in order to designate a time stamp for each team's submission.

## 2.2 Application of the module

The suggested teaching module was implemented during the Spring semester of 2019, in two concurrent sections of Soil Mechanics class, taught by two different instructors. Despite the efforts of the instructors to apply the module the same way in both sections, personal teaching style may have affected the implementation of the method. To compare the efficacy of the suggested method and the students' preference compared with the traditional approach, the new module was applied only during the second half of the semester. To evaluate the effectiveness of the suggested educational approach on student learning and engagement, students responded to a survey regarding their experience with both traditional and cooperative learning styles near the end of the semester. Between the two sections, 32% were female and 68% were male students. A total of 50 junior-level (third year undergraduate) students from both sections participated, with 32% being female and 68% male. Demographic data regarding their race have also been recorded, although they have not been associated individually with each question, at this stage. Table 1 shows the race distribution of the participants.

**Table 1. Race distribution of participating students**

| Caucasian | Hispanic or Latino | Asian or Asian American | Black | Other Race |
|---|---|---|---|---|
| 60% | 14% | 12% | 10% | 4% |

The students were asked to respond to a set of eight questions, four regarding their studying habits and their role in the group, before and after the application of the module, and four regarding their perception of the suggested module, using a system of five possible answers (strongly disagree, disagree, neutral, agree, strongly agree). Results of the student surveys conducted near the conclusion of the course are presented in the following section.

## 3 Student Responses

Broadly, the student feedback regarding the main features of the educational module, *i.e.*, working in groups, solving geotechnical problems in a game format, and competing, were positive, with a more favorable response toward the former two aspects of the educational module. Further inspection of the results revealed a number of noteworthy correlations, discussed next.

Students responded to questions regarding their preference to work individually or in groups when solving problems and studying for courses in an engineering curriculum. The results, shown in Figure 1a, suggests that prior to the experience of solving problems in groups and in a competitive game environment, a large number of students, almost 40%, were already studying with a group of friends, while 60% were working individually. This preference runs immediately counter to the majority of the activities throughout most courses in traditional civil engineering curricula, where students are assigned individual problems and assignments in the classroom, and are often required to work independently on assignments outside the classroom as well.

The gathered response in this survey instead favors allowing students to work in groups inside the classroom to solve problems, even at the junior and senior levels in college. The results also reveal that through working in groups, students' preferences shift from working individually to working in groups (Figure 1b). These preliminary results suggest that shifting from independent problem-solving activities and assignments, both inside and outside the classroom, can not only help students learn better, but also build their tendency and openness to working in a team, an important soft skill that employers increasingly demand from engineering graduates.

The above observations are further substantiated by student response to the following question: "*Which assignment mode would you prefer in order to enforce your learning*". The question was asked for in-class activities as well as for homework assignments. The results of the survey are shown in Figure 2. It can be seen that the majority of students responded that they prefer to work in groups, or to have a combination of group and individual activities, both inside and outside the classroom. Inside the classroom, student preference was overwhelmingly toward group activities, while outside the classroom students preferred to have at least some individual assignments in addition to group work. While further evidence is needed to conclude regarding efficacy of group activities inside and outside the classroom for civil engineering courses, these preliminary results support the design and delivery of education modules that follow the engaging game-format group-based activities investigated in this study.

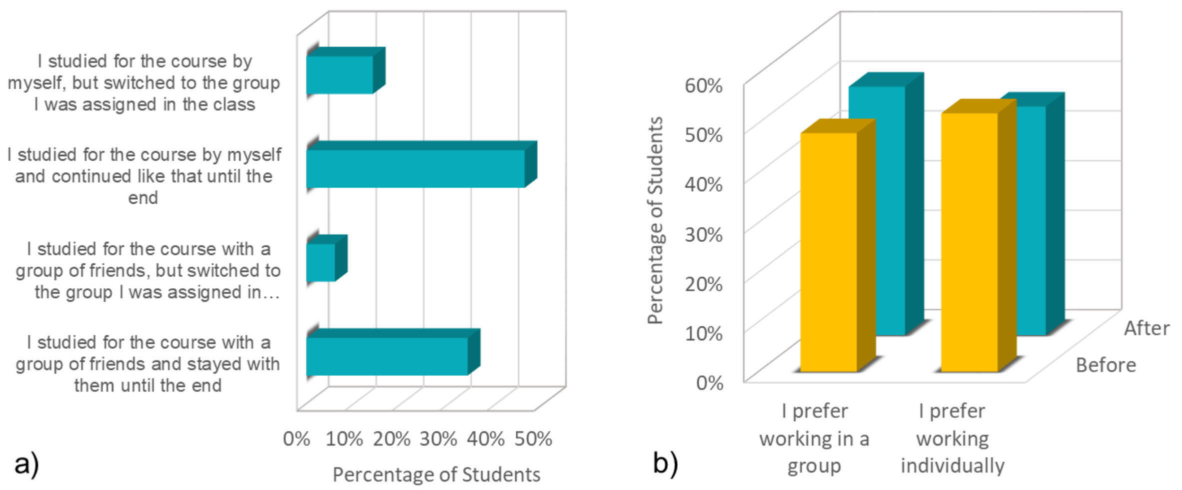


**Figure 1. Survey results regarding student preferences to work individually or in groups**

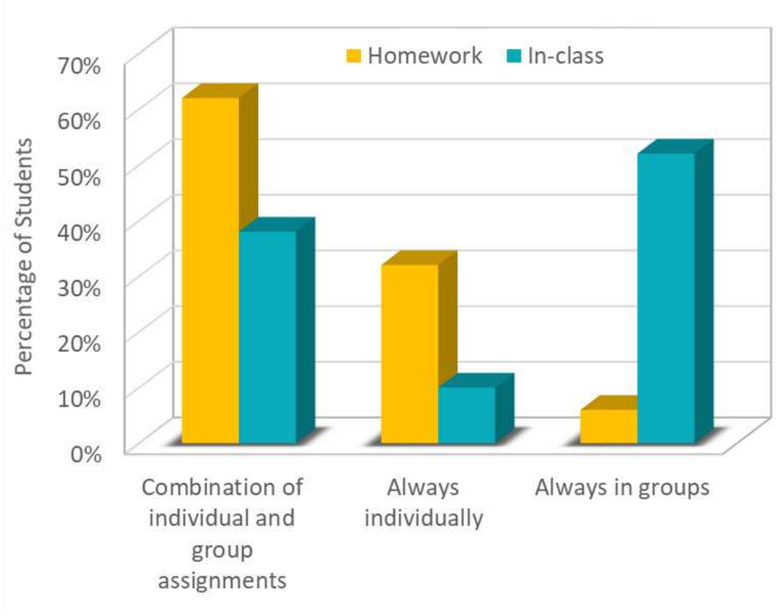


**Figure 2. Students' preference for studying individually or in groups, inside and outside the classroom**

Participation in group activities, as observed by the instructor and reported by students in the survey results shown in Figure 3, was divided. Approximately half of the students (48%) participated in solving problems, but worked individually toward the solution. The rest of the students (52%) reported either leading other group members, following their peers, or working collaboratively to solve the assigned problems. These initial observations were further analyzed by separating responses according to race and gender. The authors have data revealing that participation in group activities correlates moderately with race, and strongly with gender. This data is outside the scope of this research and are excluded from the current paper.

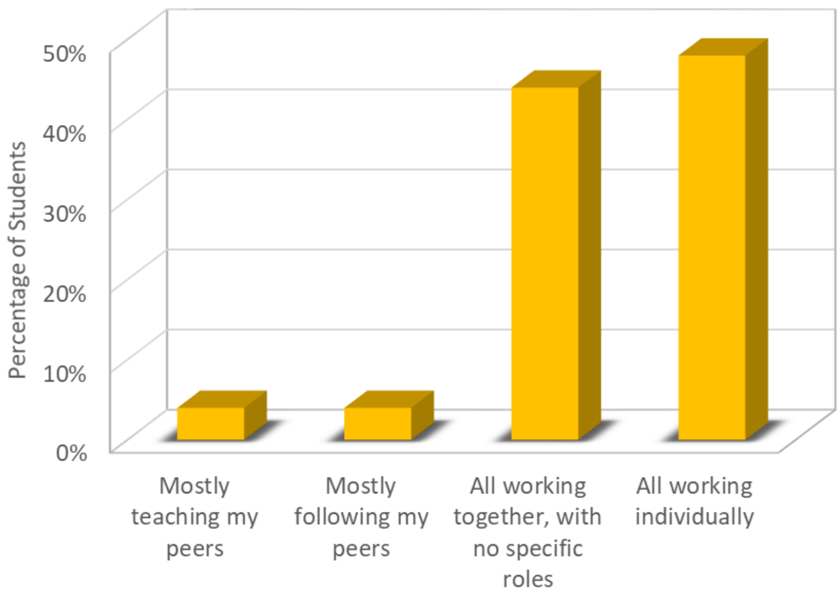


**Figure 3. Students' responses regarding their role in the study group**

As stated above, the '*game'* aspect was introduced to make learning and problem-solving more engaging and enjoyable. Students had to compete with each other to submit their answers to the assigned problems, correct and fast, with a reward of extra points. In the end, students were asked to say with which statement they could relate the most, regarding the competition aspect of this educational module. Figure 4 shows that a sizeable percentage of students (43%) were excited and studied more because of the extra points they could get. Although the goal was to make the homework and in-classroom assignments more enjoyable by applying a game-format, some students (33%) perceived it more as competitive and thus stressful. This finding aligns with the results from another survey on senior (fourth year undergraduate) students who were introduced to a competitive collaborative educational module for design courses (Ieronymaki, 2019). Finally, about 24% of the student body remained indifferent.

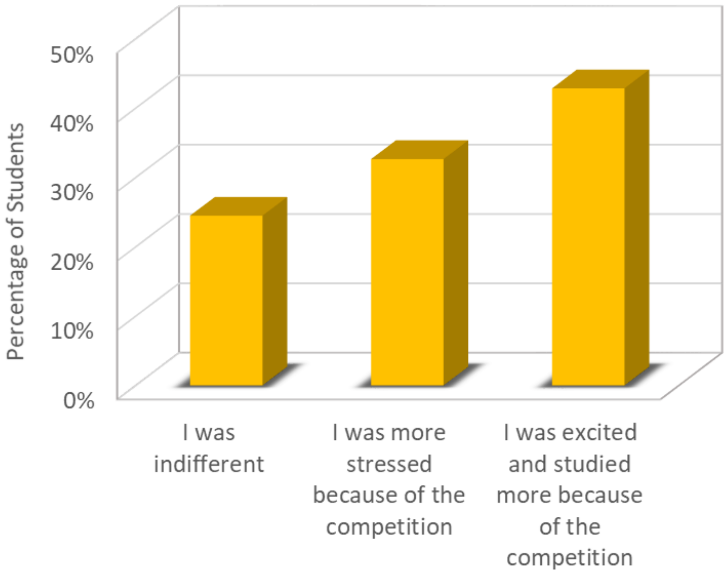


**Figure 4. Students' responses on their perception regarding the '*game*' (extra points)**

An additional question was posed to assess whether the game-aspect of the approach made the whole course more enjoyable/fun. As presented in Table 2, the majority of the students responded positively with about 52% in the strongly agree and agree category. About 38% remained neutral, while only 10% of the students responded that the competition did not enhance the fun aspect of the course. The results are not in contrast with the previous question, because the course can be more fun with the game-aspect rather than without it, even though it may be a stressful factor for the students.

**Table 2. Students' response regarding the competition**

| | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| Competing with other groups to solve problems made the class more fun (enjoyable) | 24% | 28% | 38% | 6% | 4% |

The students' perception on the game we introduced depends on two main factors; 1) the attitude a person has towards competition in general (*i.e.*, how more or less competitive a person is) and 2) the way the game is implemented in the course. The first factor cannot be controlled by the instructor as it depends on the student's personality. However, the game can be adjusted to make it less stressful, by changing the reward system or by removing the time factor. This may result in making the course more fun as the game aspect is maintained, while the stressful component of competition is rendered less prominent.

Two survey questions assessed the efficacy of group activities in enhancing students' learning of engineering concepts, the results of which are presented in Table 3. When asked whether group assignments helped students learn the concepts better, the majority of students responded positively, with 53% of the responses in the strongly agree and agree categories. However, students did not agree as strongly that group assignments helped them learn faster (39%). This suggests that while they enjoy the game component, students do not respond well to time-constrained activities, which can induce anxiety and can distract from the learning process (Ieronymaki, 2019).

**Table 3. Students' summarized response to the survey**

| | | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree |
|---|---|---|---|---|---|---|
| The group assignments helped me learn the concepts | Better | 24% | 29% | 11% | 9% | 3% |
| | Faster | 12% | 27% | 33% | 22% | 6% |

It is evident from Figure 5, that the majority of students (67%) considered the suggested module as helpful to their learning. Students responded that working in groups helped them learn concepts better by: 1) teaching concepts to their peers, 2) learning concepts from peers in their group, and 3) by a combination of learning from their peers and helping others in their group in different activities. 33% of students reported that working in groups did not help them at all. These responses provide direct evidence on the benefits of group activities in enhancing student learning of engineering concepts.

Although the *game* aspect enhances the 'fun' level of the course, it can affect the length of the lecture, and thus the amount of material that can be covered in a lecture. However, the authors found that with the suggested educational approach, fewer examples were needed in class in order to achieve the desired level of comprehension for the concepts taught. Therefore, the overall length of the lectures remained practically unaffected.

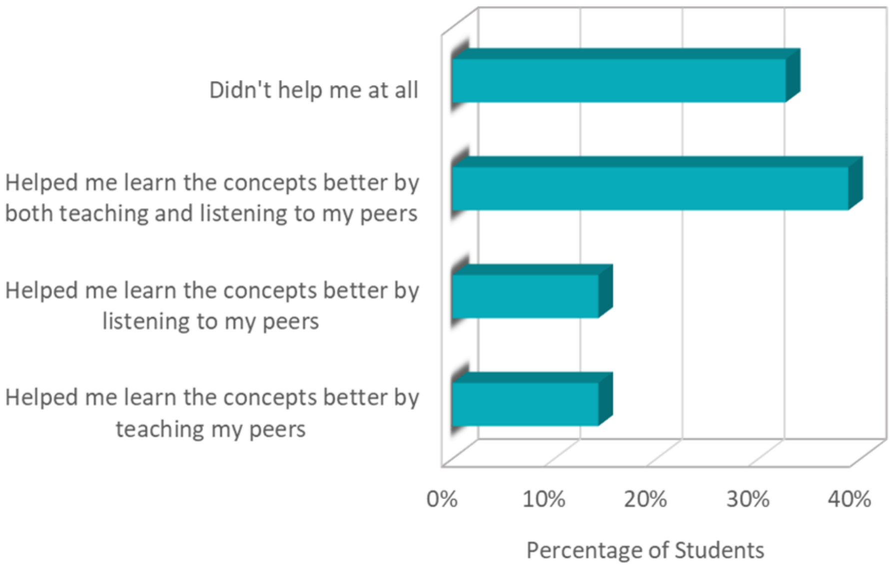


**Figure 5. Students' responses regarding the efficacy of group activities in enhancing student learning**

## 4 Conclusions

In this study, a novel educational module was proposed for undergraduate education in civil engineering courses. The module was developed for the soil mechanics course at the junior level, and can be implemented in other similar courses. Cooperative learning and game environment learning were incorporated into a traditional course structure, to encourage inductive learning. Students worked in groups to solve problems, and competed to submit correct answers. The goals of the suggested teaching approach were to: a) enhance the ability of the students to work collaboratively in groups, both in and out of class, b) create an atmosphere of achievement, as students not only learned to apply theories themselves, but also through helping and interacting with other team members, c) enhance the efficacy of problem solving in understanding of theories through collaborative learning, and d) encourage learning and engagement by incorporating a competitive component to the exercises, thereby simulating a game environment.

Students were asked questions regarding their experience with both the cooperative teaching approach, and the traditional deductive approach. Analysis of the responses revealed that the educational module encouraged students to participate in cooperative learning, by helping others in their group, and by working collaboratively on solving problems. Moreover, it was found that incorporating a game component increased effective participation in the module, while the competitive nature of the game received mixed reactions. Students found the competitive nature of some of the problems to be stressful, thereby hindering the learning experience. The preliminary findings of this study therefore suggest that cooperative learning can be effectively implemented using the educational module proposed, but with a game component that places less emphasis on competition, and more on collaboration.

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## Appendix A: Examples of in class and out of class group activities

***Example 1: In class group activity***

Topic: Effective stress principle.

Instructor introduces the effective stress principle, and solves an illustrative example with students. The instructor leads solving this introductory example. Instructor alerts students that the next problem is a group problem. The problem is introduced, and a brief overview of the solution strategy is given by the instructor. The students are given 10 minutes to work in their groups on the solution. Students gather in their groups, and work on the solution.

Problem Statement: In the soil profile shown, the GWT fluctuates seasonally within the sand layer due to precipitation. Calculate the depth of the GWT from the ground surface, Z, which will result in a vertical effective stress at point A equal to 2700 psf.

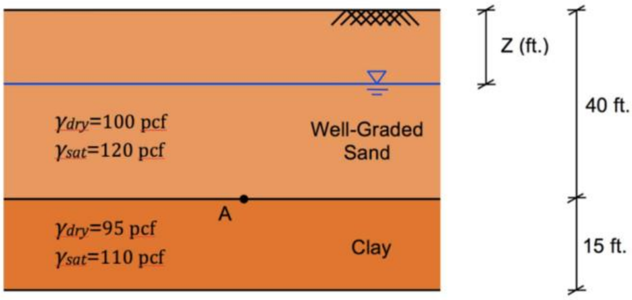


**Figure A1. Soil profile for in-class group assignment**

The instructor walks around the classroom, and checks the progress of groups. The remaining time is announced twice throughout the 10-minute period. As groups announce their solution, the instructor inspects the solution with the group. If the solution is correct, he/she records both that the correct solution has been obtained, as well as the time. If the solution is incorrect, the instructor hints to the mistake, and allows students to continue to work on the solution.

At the conclusion of the 10-minute time allocated to the problem, the instructor asks the groups with the correct solution to participate in reviewing the problem solution with the class. Another five minutes is allocated to this task. There are ten such in-class group problems throughout the semester, along with a total of 20 out of class problems in the form of group problem sets. The progress of the groups is monitored and intermittently shared with the student to encourage competition among groups.

***Example 2: Homework group activity***

Topic: Rate of Consolidation.

Instructor introduces the rate of consolidation concept in class, and solves an illustrative example. A problem set with 4-5 problems is assigned that requires students to work in groups at home and submit their solutions on an online system (Moodle), with a cut-off of 1 week from the day of the assignment.

Each group submission gets a time stamp when it is uploaded and the first group that submitted their answers first and correct, get the extra points (*e.g.*, +5 points, out of 100). The instructor announces which group gets the extra points when the problem sets get corrected. The following example is an example problem of the 'Rate of consolidation' problem set (Coduto et al., 2011).

Problem Statement: A shopping center is to be built on the fill shown in Figure A2. The proposed buildings and other facilities can tolerate a settlement due to the weight of the fill of no more than 2 in. Therefore, once the fill has been placed, it will be necessary to wait until enough settlement has occurred that the remaining settlement will be less than 2 in. Only then may the building construction begin. Assuming the fill will be placed at a uniform rate from May 1 to June 1, determine the earliest start date for the building construction. For this problem, consider only settlement due to the weight of the fill.

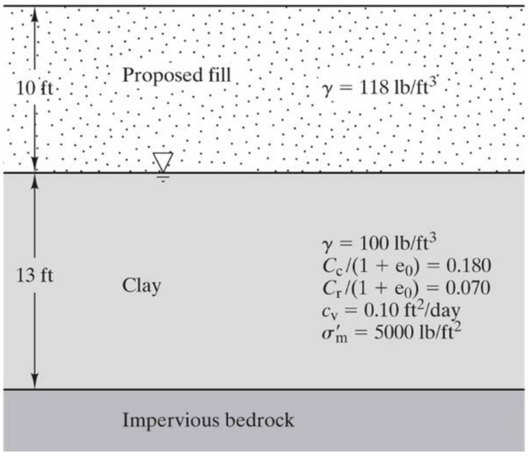


**Figure A2. Soil profile for homework group activity (after Coduto et al., 2011)**

# Authors' bios

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Eva Ieronymaki is an Assistant Professor of Geotechnical Engineering at Manhattan College New York, in the department of Civil and Environmental Engineering. She holds B.Sc. and M.Sc. degrees in Civil Engineering from the National Technical University of Athens (NTUA), Greece, and S.M. and Ph.D. degrees in Geotechnical and Geo-environmental Engineering from the Massachusetts Institute of Technology (MIT), USA. Her research deals primarily with numerical modeling, data analysis, tunneling, deep excavations and soil-structure interaction. Eva is also involved in engineering education research, investigating new methods for effective learning and engagement in junior and senior level courses of geotechnical engineering. She has received several prizes and awards, including DFI Women in Deep Foundations award (2017). Her research on teaching effectively foundation design courses drew the attention of the industry, and her work was featured in the Deep Foundations Institute magazine (January/February 2020).

***Mehdi Omidvar, Manhattan College New York, USA***

Dr. Mehdi Omidvar is an assistant professor at Manhattan College who specializes in the field of Geotechnical Engineering. He holds his Civil Engineering degree from New York University. His disciplinary research interests involve natural hazard mitigation, monitoring, and risk assessment applied to bridge scour. His team is developing tools for using autonomous underwater vehicles in bridge scour monitoring. Dr. Omidvar also specializes in experimental, analytical, and constitutive modeling applied to high strain rate loading and soil-structure interaction problems. He has received funding from the US Department of Transportation, and the Department of Defense, through the Strategic Environmental Research and Development Program. Dr. Omidvar is also a passionate and innovative educator. He has developed classroom modules to visualize modes of failure to aid limit equilibrium analysis of foundations and earth retaining walls, with funding from the United States Universities Council on Geotechnical Education and Research (USUCGER). He is also currently leading research on collaborative learning in geotechnical engineering classes. Dr. Omidvar is a past participant of the Excellence in Civil Engineering Education (ExCEEd), and the USUCGER Teaching Strategies and Resources Workshop.

***Danielle Rabadi, Manhattan College New York, USA***

Danielle Rabadi, E.I.T., is a graduate Civil Engineer with a minor in Mathematics from Manhattan College Class of 2020. She was an active student in her school as she has taken on several leadership positions throughout her college career, including: President of Structural Engineers Association of NY, Co-Project Manager for Concrete Canoe, Treasurer for DFI, and Vice-President for Society of Physics Students. For a year and a half she worked as a Teacher's Assistant for the Civil Engineering Department at MC where she set up labs for the Earth Science for Engineers course, as well as helped students study for their course work. Her previous internship involved working for Mueser Rutledge Consulting Engineers (MRCE). During the course of her internship, she collected and categorized site boring samples, and performed a rough cost analysis for a water-front project. She holds her OSHA 30-hour Construction Safety and Health certification. She is also a member of Chi Epsilon Honor Society and a (to be inducted) member of the Order of the Engineer, and was awarded the Vincent DeSimone Scholarship by the Concrete Industry Foundation.