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Key concepts in soil mechanics: simple hands-on and team-based strategies to promote active learning

Concepts clés en mécanique des sols: stratégies pratiques simples pour promouvoir l'apprentissage actif

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ABSTRACT: Soils are particulate materials, which exhibit mechanical and hydraulic responses, very different from other civil engineering materials. This response poses additional challenges to students. A new pedagogical practice was implemented, combining hands-on and team-based learning to promote deep learning of fundamental concepts in Soil Mechanics: phase relationships and total and effective stresses in soils. The implementation occurred in the first semester of 2022/2023 in an introductory course on Soil Mechanics (Civil Engineering degree) at University of Aveiro, Portugal. To illustrate the topics covered simple experiments were used, setup with basic materials and accessories, thus simple to replicate in different contexts. Most activities took place in a room with modern equipment and furniture, designed to promote active learning. The model promotes deep learning and student engagement. Students appreciated the model, the sessions dynamic, the learning environment and the interaction between peers and with teachers. They recognised the importance of adopting different learning strategies. Not all students engaged with preparation activities, which compromises the benefit from the sessions. The model is sufficiently robust and versatile to be replicated in different contexts. The authors believe that using technology, while adopting hands-on strategies (with simple physical models and illustrations) and promoting critical thinking is an excellent way of promoting engagement and deep learning in Soil Mechanics.

RÉSUMÉ: Les sols sont des matériaux particulaires qui présentent des réactions mécaniques et hydrauliques très différentes des autres matériaux de génie civil. Cette réponse pose des défis supplémentaires aux étudiants. Une nouvelle pratique pédagogique a été mise en œuvre, combinant l'apprentissage pratique et l'apprentissage en équipe pour promouvoir l'apprentissage approfondi des concepts fondamentaux de la mécanique des sols: relations de phase et tensions totales et effectives dans les sols. L'implémentation a eu lieu au cours du premier semestre 2022/2023 dans le cadre d'un cours d'introduction à la mécanique des sols (diplôme de génie civil) à l'université d'Aveiro, Portugal. Pour illustrer les sujets abordés, des expériences simples ont été utilisées, préparées avec des matériaux et des accessoires de base, donc faciles à reproduire dans différents contextes. La plupart des activités se sont déroulées dans une salle dotée d'un équipement et d'un mobilier modernes, pour favoriser l'apprentissage actif. Le modèle favorise l'apprentissage en profondeur et l'engagement des étudiants. Les élèves ont apprécié le modèle, la dynamique des sessions, l'environnement d'apprentissage et l'interaction entre pairs et les enseignants. Ils ont reconnu l'importance d'adopter différentes stratégies d'apprentissage. Tous les étudiants n'ont pas participé aux activités de préparation, ce qui compromet le bénéfice des sessions. Le modèle est suffisamment solide et polyvalent pour être reproduit dans différents contextes. Les auteurs estiment que l'utilisation de la technologie, tout en adoptant des stratégies pratiques (avec des modèles physiques et des illustrations simples) et en encourageant la pensée critique, est un excellent moyen de promouvoir l'engagement et l'apprentissage approfondi de la mécanique des sols.

Keywords: Soil Mechanics; hands-on learning; phase relationships; effective stresses.

1 INTRODUCTION

Fostering deep understanding through active learning strategies is a critical priority in the education of engineering students. Engineering is a complex domain that demands more than just a superficial acquisition of knowledge. It requires a deep understanting of fundamental principles and the ability to relate and apply them to solve complex problems that very often require innovative solutions. Active learning strategies, which require students to engage with the content, solve problems, and collaborate with each other, are essential for achieving this depth of understanding.

In this paper, a pedagogical practice is presented and described, which was designed to promote deep learning of fundamental concepts in Soil Mechanics, and that combines two different active learning strategies: hands-on learning and team-based learning.

2 METHODOLOGY

2.1 Pedagogical context

The pedagogical strategies described herein were implemented on the course Soil Mechanics I (SMI) of the 1st cycle degree *Licenciatura* in Civil Engineering of the University of Aveiro (UA), Portugal. Within the European Credit Transfer and Accumulation System (ECTS), the *Licenciatura* programme consists of 180 ECTS credits, and SMI corresponds to 6 ECTS credits. At UA, 1 ECTS is assigned to a workload of 27 hours.

2.2 Course

This is an introductory course on Soil Mechanics. The aim is that the students understand the basic concepts and the fundamental quantities associated, so they can later apply those concepts to the design of civil engineering structures. At the end of SMI, successful students should be able to: enunciate and apply the fundamental concepts of Soil Mechanics; define a laboratory test program to characterize soil samples and interpret their results; determine the stresses in a soil profile under different conditions; compare the stress state of soils with their shear strength; identify the water flow phenomena in soils and associated risks; predict settlements due to consolidation of clay soils and design systems to accelerate them; use computer programs to solve problems of Soil Mechanics; demonstrate capacity to work in teams; and communicate effectively (orally and in writing).
In 2022/2023, the SMI course had 21 students: 18 from the Civil Engineering programme and 3 from Erasmus.

2.3 Teaching and learning models

2.3.1 Overview of the models

The teaching and learning models adopted are varied; some are implemented during contact hours, are theoretical-practical (TP) and practical (P).

TP lessons are often expositive, with presentation of relevant content, and solving illustrative exercises or presenting and discussing realistic/real cases. Some lessons are prepared using team-based learning (TBL).

Some P lessons include "Explore first" activities; students carry out experiments and then relevant concepts are presented and discussed. Other P lessons are dedicated to solving exercises (simple to complex and realistic/real-life cases).

Project-based learning (PjBL), outside contact hours, is used to tackle realistic problems and includes experimental, analytical and/or numerical work.

Herein, particular focus is given to hands-on and team-based learning activities.

2.3.2 Pedagogical goal

As particulate materials, soils exhibit mechanical and hydraulic responses that are very different from other materials studied in civil engineering. This creates additional challenges to students. The pedagogical practice described herein was designed to promote deep learning of fundamental concepts in Soil Mechanics. The fundamental concepts reported in this paper are phase relationships for soils (section 3.1) and total and effective stresses in soils (section 3.2).

2.3.3 Hands-on learning

The learning activities were divided in two periods. During the first period, students carried out a simple experiment in groups, to visualise and demonstrate the chosen essential principles and concepts. In the second period, to trigger discussion and promote further learning, a team-based learning session was held combining previous knowledge, observations from the experiment and application activities (section 2.3.4).

2.3.4 Team-based learning

TBL is centred around a readiness assurance process using Readiness Assurance Tests, RAT (Koh et al., 2019). The TBL activities included: 1) preparation for the TBL session; 2) individual quiz (iRAT); 2) then, the students tackled the same quiz in a team (tRAT); 3) lastly, a discussion period in the large group, to analyse the correct answers, systematise contents and to present a final summary of the theoretical basis.

To prepare for the TBL sessions, students were invited to view online lessons on relevant topics. The lessons were developed by the authors in 2020/2021, when they taught the course using flipped learning (Pinho-Lopes and Macedo, 2022). Each online lesson includes a short video-lecture; a small question, with immediate feedback; a brief summary of key messages from the online lesson. The online lessons are available to students via the learning management system (LMS) of University of Aveiro (Moodle).

To promote deep learning, the quizzes (iRAT and tRAT) were developed to include questions ranging in complexity and mobilising varying levels of knowledge. The quizzes were designed to mix different types of questions: conceptual, about the different concepts and principles involved in the experiments; application exercises, where those are applied to particular problems. These quizzes were implemented using Microsoft Forms (Office 365). Thus, after login using the institutional credentials, each student answered individually to the iRAT. After the group discussion, one representative per group submitted their answers to the tRAT.

2.3.5 Learning spaces

Adequate learning spaces, for each type of activity, are key. The spaces used in the activities reported herein were the laboratory (for the first hands-on session) and the Space for Active Learning and Teaching (SALT) of the University of Aveiro, for the TBL sessions. SALT was created for promoting pedagogical innovation at University of Aveiro, by offering the physical, digital, and training environments necessary for the adoption of active, student-centred teaching and learning approaches. SALT provides adaptable configurations through furniture suitable for individual and group work, and different technological resources to support the activities developed.

2.4 Assessment of the models

To assess the models, different approaches can be used. First, an analysis of the students' answers to the TBL quizzes was carried out. Comparing the answers to the identical quiz given to each student individually (iRAT) and after the small group discussion (tRAT), it was possible to understand how learning evolved throughout the TBL session. This approach was used and presented in Macedo and Pinho-Lopes (2023) where a quantitative analysis is included.

Second, a survey prepared and given out at the end of each TBL session was used to collect the students' perceptions about the hands-on activities and the TBL sessions: STOP, START & CARRY ON (SS&Co) survey. The three open-ended questions that students answered anonymously and digitally were: 1) STOP. State what you do not like about SMI and WHY; 2) START. State what you would like to see improved in SMI and WHY; 3) CARRY ON. State what you like best about SMI and WHY.

In this paper, the results and discussion refer to the teachers' (the authors) and the students' perceptions on the teaching and learning models implemented. The authors reflections are included, as well as suggestions to enable other teachers to implement similar models.

3 IMPLEMENTATION AND DISCUSSION

3.1 Key concepts A – phase relationships for soils

The hands-on and TBL learning activities used for promoting deep learning of the phase relationships for soils have been described in detail by Macedo and Pinho-Lopes (2023). These activities are organised at the start of the semester, namely the first P lesson and the second TP lesson.

3.1.1 Hands-on learning

The hands-on learning activity took place at the Civil Engineering laboratory. The activity is similar to the "Jar of Rocks" demonstration proposed by Elton (2015). During the experiment students measured the mass of specimens of known volume of a gravel placed on a small jar under different conditions: dry; partially saturated; and fully saturated.

The students organised themselves in small groups (up to 3 students). They were given a laboratory sheet (without theoretical explanation, written or verbal) that included information on the sequence of activities to carry out (details in Macedo and Pinho-Lopes, 2023) and a table, to record the observations. After the experiment was finished, students received a second hand-out which included: equations that define the phase relationships for soils; information on unit conversions; a table to fill-in with the values of the phase relationships for the three specimens (dry, partially saturated, and fully saturated).

3.1.2 Team-based learning

The TBL session included a new subtopic, relations between phase relationships. Students were asked to engage with an online lesson on the topic beforehand.

The quiz used in the TBL session included four sections: 1) asking students if they watched the online lesson; 2) simple calculation exercise, similar to the one carried out during the hands-on activity; 3) conceptual questions, to promote discussion and critical thinking; 4) application exercise, using relations between phase relationships for soils. The quiz is included in Macedo and Pinho-Lopes (2023).

3.2 Key concepts B – total and effective stresses in soils

The hands-on and TBL learning activities about total and effective stresses in soils took place on a single TP lesson, at the start of the second chapter of the syllabus. Students were asked to view two online lessons before the session: Lesson 1 (Chapter 2) about stresses in soils and the principle of effective stress, and Lesson 2 (Chapter 2) covered the at-rest stress state and the at-rest earth pressure coefficient.

3.2.1 Hands-on learning

The hands-on experience was adapted from Elton (2001) using the "The Bucket of Bolts Experiment", which consists of placing loose aggregate in a bucket, surrounding bolts with nuts at the top, tightened; up turning the bucket does not result in dumping the aggregate out of the bucket. The procedures were explained verbally to students. At the start of the session, they carried out the experiment in small groups and observed the response of the aggregate, when the container was turned over.

3.2.2 Team-based learning

The TBL activities (mostly held at the second part of the session) included: 1) preparation for the TBL session (before the session); 2) individual quiz (iRAT); 2) group quiz (tRAT); 3) large group discussion.

The quiz (iRAT) developed for this TBL session is summarised in Table 1. The quiz tackled in group (tRAT) included an additional question (Table 2). The different activities had allocated times.

Table 1. Quiz (iRAT) used in the TBL session on Key concepts B – total and effective stresses in soils.

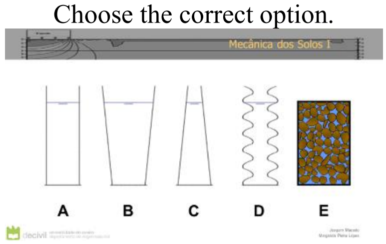
Section	Question	Type of answer
1 | Experience	Explain the phenomenon you observed in the experiment carried out at the start of the session.	Open question (text)
2 | Preparation for the session	Did you watch *Lesson No. 1 of Chapter 2 | Principle of effective stress* on e-learning?	Multiple choice (Yes | I forgot | No)
3 | Conceptual questions	3.1. Positive stresses in a soil are tensile stresses.	True / False
	3.2. The stress applied to a soil is that obtained through the forces between particles divided by the contact surface between the soil particles.	True / False
	3.3. The stress acting on the boundary of a soil element is called: a) Total stress | b) Effective stress | c) Pore water pressure	Multiple choice
	3.4. The effective stress corresponds to the portion of the pore water pressure that is actually installed in the solid skeleton of the soil.	True / False
	3.5. In a soil, the structure formed by the pores is connected to each other, forming a single continuous "body".	True / False
4 | Preparation for the session	Did you watch *Lesson No. 2 of Chapter 2 | At-rest stress state* on e-learning?	Multiple choice (Yes | I forgot | No)
5 | Conceptual questions	5.1. The stresses in the ground are due exclusively to the soil unit weight.	True / False
	5.2. In which case (A to E) is the water pressure at the base greater? Choose the correct option. 	Multiple choice (multiple answers accepted)
	5.3. Consider a homogeneous soil mass with horizontal surface and a point P located at depth z. The effective stress at this point will always be greater when the soil is dry than when it is saturated (water table at ground surface).	True / False
	5.4. In a very old clay ground that has undergone several loading-unloading cycles, the probable value of the at-rest earth pressure coefficient will be: a) Smaller than 1 | b) Equal to 1 | c) Larger than 1	Multiple choice
6 | Application exercise	The aim is to determine the at-rest stress of a homogeneous soil mass with a horizontal surface and where the water table coincides with the surface. Data: Soil unit weight 18 kN/m^3; water unit weight 9.81 kN/m^3; at-rest earth pressure coefficient K_0=0.5. For a point P at 5 m depth, calculate: a) total vertical stress | b) pore water pressure | c) effective vertical stress d) effective horizontal stress | e) total horizontal stress	Numerical

Table 2. Additional question on the group quiz (tRAT) used in the TBL session on Key concepts B – total and effective stresses in soils.

Section	Question	Type of answer
7 | Application exercise	Graphically represent the variation in depth of the stress state of the soil profile, up to a depth of 10 metres. Include the total vertical and horizontal stresses, the effective horizontal and vertical stresses and the pore water pressure on the same graph. A minimum of 5 points must be included, between 0 m and 10 m depth. Submit an excel file with the calculations and the graph.	Numerical

3.3 Results and discussion

3.3.1 Students' engagement and perceptions

The number of students actively participating in the course varied (between 15 and 17). The Erasmus students did not participate in most activities, and 1 other student did not engage at all with the course. The attendance to the sessions is summarised in Table 3.

Table 3. Attendance and engagement in the sessions.

Key concepts | session	N. of students attending	N. answers to the iRAT	N. of students engaging with the online lessons
A | hands-on session	18	-	-
A | TBL session	15	12	11: Chapter 1 | Lesson 1
B | hands-on and TBL session	15	10	8: Chapter 2 | Lesson 1 6: Chapter 2 | Lesson 2

Of the 15 students attending sessions on key concepts A and B, only some answered the iRAT. A few students forgot to login in Office 365 before attempting to answer the quiz and, thus, their answers were not recorded. This led to only 12 and 10 answers for sessions A and B, respectively. Of the students answering the iRAT, 92% prepared in advance for session A, while 60% viewed the 2 online lessons for session B (80% viewed 1 only). These numbers showed a decrease in the engagement of students with the pre-session activities, which affected their performance on both the iRAT and tRAT and how much they could gain from the TBL session.

Table 4 summarises the results of SS&Co survey.

Table 4. Results of the SS&Co survey (in %).

	Comments	A	B
STOP	Nothing / Students liked everything	50	43
	Hand-out given after the session	0	7
	No answer / Do not know	50	50
START	Nothing / Students liked everything	50	7
	More classes at SALT	33	50
	Better theoretical introduction	0	7
	No answer / Do not know	17	36
Carry on	Class dynamics / interaction	44	40
	Diversity of learning strategies	19	10
	Existence of video contents	13	5
	Real / realistic case studies	13	0
	Quality of SALT	0	15
	Hands-on activity	0	15
	Group work	0	5
	No answer / Do not know	13	10

Overall, students were happy with the course and the hands-on and TBL activities. The SS&Co survey results (Table 4) showed that the teaching and learning models implemented were well accepted by the students.

Students enjoyed the teaching space (SALT) and asked for more sessions in that room. They also appreciated the use of different teaching and learning strategies and the class dynamics associated to the hands-on and TBL activities.

3.3.2 Teachers' perceptions

The teachers' (authors') perceptions are included in two different dimensions: 1) discussion on whether the teaching and learning model adopted worked well and allowed better and deeper construction of knowledge by students; 2) how the model can be adapted by other teachers to their contexts.

These two strategies combined, hands-on and TBL, were well accepted by students. However, the pre-session activities were often overlooked by students. That is particularly relevant as the semester advances. For the case described herein, the demands of different courses reduced student engagement with the online lessons from the first to the second session. As discussed before, the lack of preparation for the sessions reduces their effectiveness and how much students gain. Another important aspect is the discussion within the groups to answer the tRAT. In some groups, a few students convinced the others of wrong answers, propagating misconceptions, and errors. These were later deconstructed during the final, large group discussion. Thus, final discussion periods are key for the success of these strategies; allocating enough time for this is essential. Time management is an issue that requires some attention. For the whole TBL process to develop, time periods appropriate to all tasks are needed. To actively involve students in the process, it is important to ensure that the session is dynamic and engaging. Therefore, the space where the session takes place must be suitable for the various activities, such as carrying out simple experiences, problem solving and discussing in small groups, and large group discussion. Finally, this methodology promotes the development of some soft skills such as teamwork, communication, problem solving.

These reflections aim at encouraging other teachers to implement similar strategies, as they are simple to implement and rather effective. The hands-on experiments are straightforward, and do not require sophisticated equipment or materials. Although the iRAT and tRAT have been implemented digitally (using Microsoft Forms), they can be done using printed versions. The digital format allows checking for changes in answers and the progress of students quickly, if that type of analysis is considered useful. The preparation activities adopted were the online lessons, previously available because of the teaching and learning strategies adopted during the COVID19 pandemics. If this type of resource is not available, alternatives need to be found, such as printed handouts. Such materials tend to be less appealing for many students. Dedicated and specially designed spaces for promoting active learning (such as SALT) are not essential for the success of the model. Ideally, the TBL session should be held in rooms where the furniture can be moved, alternating between individual, small group, and large group work.

4 CONCLUSIONS

Soils are particulate materials, which exhibit mechanical and hydraulic responses that are very different from other materials studied in civil engineering. This response poses additional challenges to students. A new pedagogical practice was implemented, combining hands-on and team-based learning (TBL) to promote deep learning of fundamental concepts in Soil Mechanics. The fundamental concepts reported in this paper are phase relationships for soils and total and effective stresses in soils. The main conclusions of this paper are:

- The model promotes active learning and student engagement during the sessions.
- Students appreciate the model, the dynamic of the sessions, the learning environment and interaction between peers and with the teachers. They recognised the importance of adopting different learning strategies.
- Not all students engaged with the preparation activities, which compromises the benefit they get from the sessions.
- Realistic allocated times for the different tasks is an essential feature for the success of this model. This is enhanced by a multifunctional space, designed for active teaching and learning.
- The model is sufficiently robust and versatile to be replicated in different contexts, regardless of the availability of technology.
- The TBL discussions, in the small and the large group, promote argumentation skills and critical thinking.
- From the teachers' perspective, the model worked well and promoted deep learning. The hands-on experiments become references that can be used when recalling concepts (often used as a reminder in later sessions).

The authors believe that using technology, while adopting hands-on strategies (with simple physical models and illustrations) and promoting critical thinking is an excellent way of promoting engagement and deep learning in Soil Mechanics.

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