# Project-Based Learning to Promote High Order Thinking and Problem Solving Skills in Geotechnical Courses

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***Abstract*—In today's society engineer professionals play a crucial role in tackling challenges such as climate change or economic constraints, in order to promote economical development and increase of quality of life ensuring principles like sustainability or safety. It is fundamental to prepare the future engineers to these and future challenges. According to the literature, traditional engineering educational strategies used to prepare the future engineers (lectures, lab experiences and homework) have two main drawbacks. Firstly, they inadequately prepare engineering students to engage in collaborative partnerships (essential for the practicing engineer) and, secondly, they promote passive learning and contribute to a compartmentalized curriculum. As such, the traditional deductive learning may not adequately prepare students for their innovative and flexible role as future engineers. An alternative approach is the use of non-traditional learning strategies, as in the case study hereby presented. Active learning strategies, namely project-based learning, were used to contribute to enhancing problem solving and higher order thinking skills of the graduates in Civil Engineering program of University of Aveiro, Portugal. Seizing the opportunity created by the Bologna process, two complementary courses on Geotechnical subjects (Soil Mechanics I and II) have been redesigned. The non-traditional strategies implemented include project-based learning using cooperative and collaborative models, put into practice since 2007/2008. The learning strategies referred are described and discussed. Their contribution to the development of problem solving and high order thinking skills of students is pointed out. Several strategies used to promote acceptance by students are put forward. The models were assessed using three strategies: students' feedback during the semester; academic performance; questionnaires at the end of the semester. The evolution of the students' response to these models is discussed using data collected in the courses. The models have been adapted to overcome some of the difficulties faced during their implementation.**

***Index Terms*—Collaborative model, cooperative model, high order thinking skills, problem solving skills, project-based learning.**

## I. INTRODUCTION

According to [1], "higher education needs to provide challenging yet supportive learning environments catering for students with diverse academic needs". This paper refers to an attempt of implementing such environment in two Geotechnical courses. As geotechnical problems oblige engineers to routinely use critical thinking and engineering judgment [2], courses on Geotechnics are ideal to promote such skills using realistic projects.

In this paper, reflections on two Geotechnical courses, Soil Mechanics I and II (Civil Engineering programme of University of Aveiro, Portugal) are included and several issues regarding the implementation of project-based learning strategies are discussed. The courses were redesigned using a constructivist approach by promoting active learning, using a cooperative or a collaborative model focused on project-based work.

This paper addresses the following research questions:

- *Are the active learning strategies useful to promote and facilitate the construction of knowledge and the development of competencies by students?*
- *How these strategies can contribute to the development of problem solving and high order thinking skills?*

## II. BACKGROUND

A constructivist approach to education is focused on presenting new information to students, in the context of their previous knowledge, and on helping them to develop understanding and skills, through activity and reflection [3]. The bases for such a student-centred approach to teaching are the students. Understanding their diversity and how to address them while preparing a program or course is, thus, essential. Additionally, according to [4], to promote active-learning an academic needs to value a student as a person within the learning process.

Three conditions of effective learning were reported by [5]: active learning by doing, cooperation and teamwork in learning and learning through problem solving. The last is considered essential to foster creativity and innovative capacity and a critical skill for engineering students [5].

Project-based learning can help to promote such skills in engineering programs [6]. With such strategy the teachers try to recreate professional reality and allow relating fundamental theories and skills of an engineer. Moreover, an important component of the professional activities of an engineer is the development of projects (with differences in time scales and levels of complexity). Introducing future engineers with the combined use of spreadsheets and computing encourages a critical attitude towards the use and the results from computing and software and is essential for achieving an adequate preparation for the professional life [7].

High-level thinking and sound judgment is developed through accumulated authentic professional experience by engineers [2]. Similarly, their growth can be promoted in engineering students by creating a teaching environment which enables learning opportunities that both simulate and stimulate it [2].

High order thinking skills are usually associated with Bloom's taxonomy of skills and while some authors ([8] cited by [9]) suggest the two highest level should be addressed to in the teaching, others [10] refer the importance of working from the lower to the higher levels, to allow students to be successful at the highest.

A revised Bloom's taxonomy [11] of skills includes six levels with knowledge and cognitive process dimensions (as presented by [9]): remember, understand, apply, analyse, evaluate and create. Curricula development should address these skills and the assessment of the students' performance should integrate these different dimensions. One way of achieving it is by using learning outcomes, which define what the students should know and be able to do at the end of a learning process (program, course, module, etc.). According to [1] a clear link between what students expect to learn and how they are required to demonstrate this learning should be done. For that a variety of assessment strategies and tasks should be defined, relating directly to the learning outcomes. An assessment for learning, as opposed to the assessment of learning, is preferred ([1]).

## III. CASE STUDY

### A. Soil Mechanics courses

This paper refers to two Geotechnical courses of the Civil Engineering degree in University of Aveiro (UA): Soil Mechanics I and II. Each one corresponds to 6 ECTS and has 60-90 students per school year. One ECTS, European Credit Transfer System, credit unit represents 25 to 28 hours work (UA adopted 27 hours), including, besides class time, individual study time, preparation of reports, bibliographical research, preparation of examinations, etc.

The aim of Soil Mechanics I (SMI) is to promote the understanding of basic concepts and fundamental quantities of Soil Mechanics to be applied later in the design of civil engineering structures. The weekly timetable consists of one theoretical-practical lesson (with up to 45 students and duration of 2 hours) and one practical lesson (limited to 25 students and duration of 2 hours). The syllabus of Soil Mechanics I is grouped into: 1) Physical properties and soil identification; Sedimentary and residual soils; 2) Stress state in soils; Capillarity; 3) Water in soils; Seepage; 4) Compressibility and consolidation of clay soils.

The Soil Mechanics II (SMII) course deals mainly with the mechanical behaviour of soils. This course encompasses concepts, theories and methods generally used for the design of civil engineering structures. Emphasis is placed on works where the stability depends essentially on the soil's strength. Field tests generally used to characterize the mechanical behaviour of soils are also presented. The weekly timetable consists of two theoretical-practical lessons. The Soil Mechanics II course syllabus is grouped into: 1) Introduction to shear strength of soils; Shear strength and stress-strain relationships in sands and in clays; 2) Lateral earth pressures; Earth retaining structures; 3) Stability of slopes and embankments; 4) Sampling and *in situ* tests.

### B. Project-based learning models

The courses were redesigned in 2007/2008 which included defining the competences to be developed by students during the course and the intended learning outcomes (associated with each chapter of the syllabus). This helped to plan lessons, choose problems to be solved in-class and to prepare the projects. The assessment strategies were defined relating directly to those learning outcomes, trying to achieve an assessment for learning.

The project-based learning models used comprised:

- Traditional lectures, to introduce the relevant concepts (in theoretical-practical lessons, which including solving some simple textbook exercises), in-class discussions and questioning;
- Practical lessons, where students used hand calculations to solve problems linked to the each aspect of the syllabus (only for Soil Mechanics I);
- Compulsory team projects;
- Oral presentations and discussion sessions;
- Individual marks on the team projects, obtained using the students' self and peer-assessment.

A case study, reported by [12], showed a large majority of students considered lectures beneficial for their learning and were not an "out-of-date mode of education". In the SMI and SMII courses a lecture-base was kept and was further enhanced and complemented by project-based activities, developed mostly outside the classroom. To enable it, in-class tutorial sessions and additional tutoring moments with the teams were organised.

The learning models used have been evolving by addressing the main difficulties felt by both students and teachers and responding to the changes in the teaching team. Initially a cooperative model was implemented (SMI and SMII 2007/2008; SMI 2008/2009 and 2011/2012); a similar (though simpler) collaborative model was used in other editions of the courses.

### C. Cooperative model

In the editions where the cooperative mode was used ([13] and [14]) the projects were prepared in groups of four students with specific individual functions (laboratory / informatics technician, analyst, reporter and coordinator) in each assignment and mandatory rotations. This way all students performed the four established functions (a different one in each project), representing the corresponding role – jigsaw project system.

Depending on the project, one student was the laboratory technician, who had to carry out laboratory tests to identify and characterize a soil sample, or the informatics technician, responsible for using numerical tools, such as programs with the finite element method, namely the Geostudio package. The tasks of writing spreadsheets, using Excel or equivalent, and analysing, interpreting and discussing the results obtained were done by a second student, the analyst. The reporter (3$^{rd}$ student) was responsible for the preparation of the written part of the project, which included a short state of the art and a description of the work of his/her colleagues. The 4$^{th}$ student, the coordinator, had to organize the group, guaranteeing that all members followed the deadlines and exchanged information. In some editions the team coordinator also had to read and summarise a scientific paper in English on the projects' subject.

These roles were defined in order to ensure a parallel to functions normally fulfilled by engineering professionals. Areas of expertise were defined, corresponding to the several roles of the students (literature review, theory, experiment, data analysis, etc.). At the beginning of the semester, students assigned with a particular task were put together in expert groups and each group received specialized training, resources and checklists. Each team member had to make sure that his/her area of expertise was covered adequately in the team project. Later, students shared their knowledge and experience with their colleagues (in or outside their team) to pass them on.

To allow students to fulfil the different roles defined, each project included preparing a short state of the art on the subject, carrying out laboratory tests or performing numerical simulations, doing calculations using theoretical solutions and comparing and criticizing their results. When possible, the same geotechnical problem was used throughout the semester, allowing students to analyse different perspectives of the same problem. Further details on the projects, particularly related to using computing and software, can be found in [7].

### D. *Collaborative model*

The collaborative model was a "lighter" version of the cooperative one, for both teachers and students. The collaborative model was used mostly when only one teacher was delivering the course, included, generally fewer team projects (one to two) and the roles to be played by students were not imposed. As such, the team as a whole was responsible for all the work, having to better organise and distribute tasks. The projects proposed under this model did not include preparing a state-of-the-art.

### E. *Group formation and assessment*

The students were grouped by the teachers using their answers to a questionnaire on the marks obtained in previous courses and the time availability for group work. The aim was organising heterogeneous and balanced groups, each including students of different levels and with compatible schedules.

Grouping the students caused some complaints. In some more extreme cases (namely in the first experiences of implementation of the learning models) teachers had to intervene, by enabling some groups to discuss and helping them better organize themselves. The strategies used to resolve such conflicts followed suggestions by [15] and two types of approaches were used: 1) brief sessions in the theoretical-practical lessons to discuss typical problems, followed by in-class small group brainstorming and sharing of strategies (one per semester was sufficient); 2) promotion of meetings of teams in conflict with a teacher, to facilitate the dialogue and to define problem solving strategies. In some cases one meeting was enough; however, in other, it was necessary to join up the group in conflict with a teacher more times [13]. These groups were more closely supervised, to observe if and when the approaches used to overcome conflicts had been successful. The peer assessment after each project allowed confirming such success.

The assessment system implemented was defined using suggestions by [15] and included two assessment elements, summarised in Table I: team projects (P), developed during the semester, and tests (T). For the students who failed there was a second chance of passing – final exam, in which the team projects' mark was still considered. Depending on the course and on its edition, the number of team projects and tests varied, as well as their relative weight on the final mark. The minimum mark (MM) in each assessment element for approval also varied in the different editions.

TABLE I.
SUMMARY OF THE LEARNING MODELS AND ASSESSMENT ELEMENTS USED

| Course | Edition | Model | No. of P[a] | No. of T[b] | Weight on the final mark (%) | | MM[c] |
|---|---|---|---|---|---|---|---|
| | | | | | P[a] | T[b] | |
| SMI | 2007/2008 | Cooperative | 4 | 1 | 25 | 75 | 7 |
| | 2008/2009 | Cooperative | 4 | 1 | 40 | 60 | 8 |
| | 2009/2010 | Traditional[d] | - | 2 | - | 100 | 7 |
| | 2010/2011 | Collaborative | 2 | 2 | 25 | 75 | 7 |
| | 2011/2012 | Cooperative | 4 | 1 | 40 | 60 | 8 |
| | 2012/2013 | Collaborative | 4 | 1 | 40 | 60 | 8 |
| SMII | 2007/2008 | Cooperative | 4 | 1 | 40 | 60 | 8 |
| | 2009/2010 | Collaborative | 1 | 2 | 20 | 80 | 7 |
| | 2010/2011 | Collaborative | 2 | 1 | 25 | 75 | 7 |
| | 2011/2012 | Collaborative | 1 | 2 | 30 | 70 | 8 |
| | 2012/2013 | Collaborative | 1 | 1 | 30 | 70 | 8 |

[a] P - Team projects; [b] T - Tests; [c] MM - Minimum mark in each assessment element, for approval; [d] Traditional model: expositive lectures (theoretical-practical lessons), and solving textbook problems (practical lessons).

All team members had to orally present part of the work and answer questions from both teachers and colleagues, regardless of their function on that project.

Individual accountability was also promoted using the tests, which covered all subjects of the syllabus, and individual marks on the team projects. Such marks were obtained by applying a weight to the team's mark, based on the students' self and peer assessment within the group (according to [15]).

### F. *Team projects*

The team projects were open-ended assignments, which aimed at promoting critical thinking and engineering judgments by students. Realistic geotechnical cases were used, adapted to their level of knowledge.

"The Three S's" structure (reported by [16] as a good structure for cooperative learning assignments) was used: 1) Same problem; 2) Specific choice; 3) Simultaneous report. With the same base problem to solve, students were given (different) soil samples to be tested by each team, including a granular and a fine-grained soil. The amount of work and degree of difficulty of each team's problem was similar. Using different soil samples led to different geological profiles for each team and different decisions to be made. Assigning different values for distances, soil properties and loads and their combination created specific situations for each team.

Most projects included creating spreadsheets to compute, compare and analyse results. Additionally, numerical tools (student license GeoStudio package) of commercial software currently used by engineers when studying geotechnical problems were used [7]. Students were also encouraged to use the spreadsheets they prepared and the available software (which enabled validating the spreadsheets) to derive solutions for the problems proposed in class.

Further details on the team projects are given by [7].

### G. Strategies used to promote problem solving and high order thinking skills

Spatial and temporal heterogeneity and uncertainty of soil properties are higher than for other materials [2], resulting in the uniqueness of each geotechnical project. Such feature must be emphasised to students [17]. More than lecturing, in these courses that was also achieved by allowing students to test samples, estimate properties, review their estimates and discuss them (with other teams and teachers). The aims were enable students to formulate opinions and justify and defend them.

For each assignment the teams had to make some engineering judgment, for example in the estimation of soil properties not determined directly by the laboratory tests done, for example the Young modulus and Poisson coefficient of the samples. The team's options had to be conveniently justified and, when necessary, the quantities determined in previous assignments could be adjusted or corrected. A critical analysis of the results and their relative values was expected.

Frequently students were asked to choose different values for certain properties' values (for example, the coefficient of permeability of soils), to justify their choices and to carry our parametric analysis, using ranges of values and comparing and discussing results.

As students had to create their own spreadsheets, they were able to use them to carry out simple parametric analysis. In some projects (SMII) they generated data to understand the influence of chosen parameters on the stability of gravity retaining walls. Students were also asked to carry out some scenarios analysis where, for example, the width of a retaining wall was designed in order to find the minimum value while satisfying all external stability requirements.

To stimulate students and to allow them to work on their own, freeware versions of commercial software (in English) were used.

The use of computing and software is essential to study slope stability. The normal method of slices and methods of Bishop, Janbu and Morgenstern-Price were used and their results were compared. Students solved one particular case (one method and one possible failure surface) both by hand and using the software, critiquing the results and identifying possible causes for differences.

In most projects students were asked to analyse the differences of results obtained with different tools (spreadsheets and software) and to quantify and explain such differences, putting forward sustained hypotheses.

Non-marked activities, as using those tools to derive solutions for textbook problems or for those proposed in the lessons, were also proposed. In some cases students generated such data and discussed them with the teachers, using it to obtain solutions for the exercises.

Before these courses students had not encountered the finite element method, which can be a real obstacle for using the software. A simplistic explanation of the finite element method was given, for example in order to allow students to understand the need of manipulating the mesh, refining certain areas. The main goals were to gain a sense of the tools' limitations, as well as their dependence on the quality of the input of the materials' properties.

To introduce the software the teachers followed tutorial videos step by step during the lessons, while students followed and recreated models using their laptops. Utilising the software on their own with guidance and support from the teachers for a simple example with a known solution helped them to validate that simulation, trust their ability to utilize it and more confidently develop the models necessary for their team project. The importance of validating computer simulations and geotechnical software was pointed out by [18]. Those authors ([18]) also referred a strong need to define procedures and guidelines to arrive at reliable numerical methods and, more importantly, input parameters which represent accurately the strength and stiffness properties of the ground in situ. With the team projects students had the opportunity to realise its necessity and to practice it.

## IV. ANALYSIS AND DISCUSSION

### A. Assessment

To evaluate the success and impact of these models on students' learning, different and complementary strategies have been used: students' feedback during the semester; academic performance; and questionnaires at the end of the semester.

During the semester students were asked to give an informal opinion on the model (orally and written, anonymously). A statistical analysis of the number of students enrolled, who attended, were evaluated and obtained passing mark was done. Questionnaires were prepared and divided into two large blocks referring to: 1) course organization and implementation; 2) functioning of the teams during the projects. For most questions a five-point Likert scale was used. The data referring to the initial versions of cooperative learning model were presented by [13], for Soil Mechanics I 2007/2008 and 2008/2009, and [14] for Soil Mechanics II 2007/2008. Part of such data is summarised in this paper.

Simultaneously in University of Aveiro to both monitor and to improve the quality of teaching, a quality assessment system (SGQ) has been implemented. This includes questionnaires to students about all the courses they attend. Though smaller, these questionnaires also give pertinent information that can be used to assess the relevance and impact of the learning models implemented. These results are presented and discussed.

### B. Results

Relative to the academic performance the results achieved and summarised in Table II show the percentage of students with a passing mark was high. The academic performance was always high (minimum value of 75% in 2007/2008 with a cooperative model). This first edition is the one with higher percentage of fail marks (21%) and quits (4%). These high values can partially be explained by the expectations some students had that these models would not be used in the following editions of the course. They were expecting to retake the course on the following year with less workload. Using the edition where the traditional learning model was used as a reference, the influence of the project-based learning models in increasing the percentage of students passing is clear (with exception of the 1st edition, 2007/2008). Apart from the exception referred, the percentage of students failing is significantly lower using active learning models than for the traditional model. In the project-based learning models students are forced to study and tackle the projects during the semester.

For those who would prepare for the exam just before it, these models may play an important role in their attitude and thus deepen their knowledge

Using the project-based learning models has increased the average final mark of students and its uniformity, relatively to the traditional edition (2009/2010). When another form of assessment (other than exam) is introduced students' marks tend to increase. Additionally the relative weight of the projects is different in each edition. A more detailed analysis is thus still necessary.

Another assessment strategy used was the questionnaires at the end of the semester. Table III summarises some of the results obtained from those questionnaires for the cooperative learning model for Soil Mechanics I 2007/2008 and 2008/2009 ([13]), and for Soil Mechanics II 2007/2008 ([14]).

TABLE II.
ACADEMIC PERFORMANCE OF THE STUDENTS (SMI)

| Edition | Model | NES | NSA | Pass | Fail | Quit | Final Mark | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | *Average* | *SD* |
| 2007/2008 | Cooperative | 91 | 77 | 58 | 16 | 3 | 10.84 | 2.36 |
| 2008/2009 | Cooperative | 63 | 56 | 52 | 4 | 0 | 11.16 | 2.03 |
| 2009/2010 | Traditional | 65 | 57 | 47 | 10 | 0 | 10.58 | 3.10 |
| 2010/2011 | Collaborative | 82 | 69 | 61 | 8 | 0 | 11.45 | 2.84 |
| 2011/2012 | Cooperative | 70 | 61 | 57 | 2 | 2 | 11.76 | 1.62 |
| 2012/2013 | Collaborative | 59 | 49 | 44 | 5 | 0 | 11.49 | 2.11 |

NES Number of enrolled students
NSA Number of students assessed
SD Standard deviation

TABLE III.
SUMMARY OF RESULTS FROM THE QUESTIONNAIRES [13, 14].

| Course | | Q1 | Q3 | Q6A | Q6B | Q6C | Q10 | Q13 | Q14 | Q15 | Q16 | Q17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SMI 2007/2008** | *NVA* | 31 | 30 | 31 | 31 | 31 | 30 | 31 | 30 | 31 | 31 | 31 |
| | *Average* | 3.52 | 3.13 | 2.45 | 3.39 | 3.71 | 3.40 | 2.90 | 3.10 | 3.84 | 3.52 | 3.77 |
| | *SD* | 0.57 | 1.01 | 1.36 | 0.72 | 0.82 | 1.13 | 1.49 | 1.30 | 1.42 | 1.24 | 0.99 |
| **SMII 2007/2008** | *NVA* | 67 | 63 | 67 | 65 | 66 | 59 | 66 | 65 | 64 | 65 | 65 |
| | *Average* | 3.65 | 3.38 | 2.52 | 3.58 | 3.74 | 3.78 | 2.71 | 2.72 | 3.91 | 3.55 | 3.55 |
| | *SD* | 0.54 | 0.68 | 1.12 | 0.83 | 0.69 | 0.81 | 1.27 | 1.14 | 1.14 | 0.83 | 0.81 |
| **SMI 2008/2009** | *NVA* | 55 | 51 | 55 | 55 | 54 | 47 | 55 | 55 | 51 | 52 | 52 |
| | *Average* | 3.75 | 3.45 | 2.58 | 3.55 | 3.54 | 3.85 | 2.58 | 2.85 | 3.84 | 3.67 | 3.62 |
| | *SD* | 0.62 | 0.83 | 1.49 | 0.81 | 0.95 | 0.98 | 1.23 | 1.18 | 1.26 | 1.04 | 0.91 |

NVA Number of valid answers
SD Standard deviation
Q1 Degree of difficulty of the course (1 – Very easy; 5 – Very hard)
Q3 Adequacy of the assessment methods to the defined objectives (1 – Lower; 5 – Higher)
Q6A Adequacy of the proposed activities to the course contents – work volume appropriate to the available time (1 – Lower; 5 – Higher)
Q6B Adequacy of the proposed activities to the course contents – degree of difficult/complexity (1 – Lower; 5 – Higher)
Q6C Adequacy of the proposed activities to the course contents – interest e relevance (1 – Lower; 5 – Higher)
Q10 Proper group functioning (1 – Lower; 5 – Higher)
Q13 The teachers should interfere more in the groups' internal organization (1 – Less; 5 – More)
Q14 The teachers should interfere more in the groups work (1 – Less; 5 – More)
Q15 Does the groups' formation by the teachers have influence on the team projects final marks (1 – Little; 5 – Much)
Q16 Personally, did you admire, learn or absorb some competence (people, organization, motivation, written communication, presentation in group) from another group colleague? (1 – Little; 5 – Much)
Q17 With the implemented teaching and learning model in the course, did you learn something else beyond the corresponding formal contents? (1 – Nothing; 5 – Much more)

The majority of the students who answered the questionnaire considered that the degree of difficulty was medium to high (Q1) and that the assessment methods were adequate to the defined objectives (Q3). The item most criticised by students was the workload (Q6A), which was considered excessive for the available time, although they thought that the proposed activities were interesting and relevant (Q6C), even in terms of degree of difficulty and complexity (Q6B). Nevertheless, the answers referring to the workload (Q6A) have a coefficient of variation of 44% to 56%, showing the scatter of opinions. The students were asked about the teachers' interference in the team's internal organisation and in the project's development. No clear conclusion could be put forward as the corresponding coefficients of variation ranged from 41% to 51%. The analysis of students' answers allowed establishing they considered the team formation by the teachers had a significant influence on the final marks of the projects (Q15), although they considered that the functioning of the groups was appropriated (Q10). Finally, the students answering the questionnaire considered, almost unanimously, the implemented learning model also led to the development of skills and knowledge other than the formal course contents (Q16 and Q17). Some questions were also introduced about the projects' added value to their preparation for future engineering work. It was somehow consensual among students that this model has advantages in their preparation for "real life" and for their future role as civil engineers.

The SMI course has been assessed by students using SGQ in its editions of 2007/2008 (cooperative model), 2009/2010 (traditional), 2010/2011 (collaborative model), 2011/2012 (cooperative model) and 2012/2013 (collaborative model). The number of answers obtained and the students' perception of the ECTS of the course are presented in Table IV.

It is clear that with the cooperative model the workload referred by students is similar to the assigned to the course (6 ECTS); while with the other methods it is clearly insufficient. In 2012/2013 the collaborative method was adapted to follow the structure of the cooperative model (the main differences were the formation of the groups by the students and the non-mandatory roles), which resulted in a very good approximation to 6 ECTS.

TABLE IV.
SGQ RESULTS - ECTS ESTIMATED BY STUDENTS (SMI)

| Edition | Model | NES[a] | NVA[b] | Estimated ECTS | |
|---|---|---|---|---|---|
| | | | | *Average* | *SD*[c] |
| 2007/2008 | Cooperative | 91 | 39 | 6.3 | 3.4 |
| 2008/2009 | Cooperative | Data not available | | | |
| 2009/2010 | Traditional | 64 | 38 | 4.57 | 1.24 |
| 2010/2011 | Collaborative | 68 | 51 | 4.71 | 1.73 |
| 2011/2012 | Cooperative | 67 | 43 | 6.77 | 2.93 |
| 2012/2013 | Collaborative | 58 | 36 | 6.05 | 2.29 |

[a] NES - Number of enrolled students (eligible to SGQ); [b] NVA - Number of valid answers; [c] SD - Standard deviation

The SGQ and its questionnaires have been changing through the years. Therefore it is difficult to do a direct comparison of results between editions. Table V and VI include the results for the editions of 2007/2008 and 2009/2010 to 2012/2013, respectively, of the SMI course. In 2008/2009 the number of answers collected was not sufficient for the system to validate the results.

From these results, which reflect the students' perceptions, when compared to the traditional approach (2009/2010), using the collaborative (2010/2011 and 2012/2013) and the cooperative models (2011/2012) has increased: the coordination between the different components of the course (P7); the adequacy of the recommended study elements and bibliography (P8); the adequacy and modernity of the equipment, as laboratory, computer rooms, etc. (P10); the inclusion of information in virtual secretary and e-learning environments (P11); the degree of difficulty of the course's contents (P16), despite being exactly the same; the workload or time necessary to obtain a pass mark (P17). The collaborative assessment method (P13) was considered more adequate than the cooperative one, although when compared to the traditional both are considered less adequate. For the adequacy of the proposed activities (practical cases, homework) to the course and its objectives (P9), for the development of the comprehension skills on the themes covered (P14) and for the articulation between the activities carried out in the course and the competences previously acquired (P15), the collaborative model was considered more adequate than the traditional one, though the opposite occurs with the cooperative model. Globally students perceived the course has functioning better with the collaborative model, followed by the traditional and the cooperative ones (P12 and TTG).

TABLE V.
SGQ RESULTS FOR SMI IN 2007/2008 (ANSWERS' SCALE FROM 1, LOWEST, TO 5, HIGHEST).

| Course | | NVA | G1 | G2 | G3 | G4 | G5 | G6 | G7 |
|---|---|---|---|---|---|---|---|---|---|
| **SMI (Cooperative)** | ***Average*** | 45 | 3.4 | 3.8 | 3.8 | 3.0 | 3.2 | 3.1 | 2.3 |
| **2007/2008** | ***SD*** | | 1.10 | 1.03 | 1.18 | 1.21 | 1.13 | 1.16 | 1.31 |

| | |
|---|---|
| NVA | Number of valid answers |
| SD | Standard deviation |
| G1 | Coordination of the different components (theoretical, practical, theoretical-practical, laboratory, …) |
| G2 | Adequacy of the recommended study elements and bibliography |
| G3 | Access to the study elements |
| G4 | Articulation between the activities carried out in the course and the competences previously acquired |
| G5 | Articulation between the activities carried out in the course and its objectives |
| G6 | Adequacy of the assessment method to the courses' objectives |
| G7 | Adequacy of the workload demanded to the course ECTS |

TABLE VI.
SGQ RESULTS FOR SMI IN 2009/2010, 2010/2011; 2011/2012 AND 2012/2013 (ANSWERS' SCALE FROM 1, LOWEST, TO 9, HIGHEST).

| Course (Model) | | NVA | P7 | P8 | P9 | P10 | P11 | P13 | P14 | P15 | TTG | P12 | P16 | P17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SMI (Traditional)** | ***Average*** | 38 | 6.16 | 6.57 | 6.12 | 5.16 | 6.65 | 6.58 | 6.36 | 5.86 | 6.23 | 6.72 | 5.65 | 6.50 |
| **2009/2010** | ***SD*** | | 1.32 | 1.67 | 1.36 | 1.57 | 1.65 | 1.34 | 1.22 | 1.33 | 1.48 | 1.19 | 1.40 | 1.50 |
| **SMI (Collaborative)** | ***Average*** | 51 | 6.80 | 6.76 | 6.75 | 6.32 | 7.24 | 6.33 | 6.54 | 5.86 | 6.58 | 7.24 | 6.53 | 7.51 |
| **2010/2011** | ***SD*** | | 1.34 | 1.59 | 1.78 | 1.37 | 1.34 | 1.89 | 1.43 | 1.49 | 1.58 | 1.37 | 1.42 | 1.07 |
| **SMI (Cooperative)** | ***Average*** | 43 | 6.37 | 6.67 | 6.02 | 6.51 | 6.81 | 5.26 | 6.20 | 5.95 | 6.22 | 6.14 | 6.05 | 7.76 |
| **2011/2012** | ***SD*** | | 1.80 | 1.44 | 1.91 | 1.52 | 1.44 | 1.83 | 1.17 | 1.31 | 1.63 | 1.60 | 1.11 | 1.23 |
| **SMI (Collaborative)** | ***Average*** | 36 | 7.25 | 6.92 | 7.06 | 6.51 | 6.78 | 6.42 | 6.81 | 6.31 | 6.76 | 7.25 | 6.75 | 6.92 |
| **2012/2013** | ***SD*** | | 1.34 | 1.38 | 1.43 | 1.46 | 1.71 | 1.65 | 1.26 | 1.39 | 1.47 | 1.30 | 1.00 | 1.27 |

| | |
|---|---|
| NVA | Number of valid answers |
| SD | Standard deviation |
| P7 | Coordination of the different components (theoretical, practical, theoretical-practical, laboratory, …) |
| P8 | Adequacy of the recommended study elements and bibliography |
| P9 | Adequacy of the proposed activities (practical cases, homework) to the course and its objectives |
| P10 | Adequacy and modernity of the equipment (laboratory, computer rooms, etc.) |
| P11 | Inclusion of information in PACO (virtual secretary) and e-learning |
| P13 | Adequacy of the assessment method |
| P14 | Development of the comprehension skills on the themes covered |
| P15 | Articulation between the activities carried out in the course and the competences previously acquired |
| TTG | Total of groups P7-P15, except P12 |
| P12 | Global functioning of the course |
| P16 | Degree of difficulty of the course contents |
| P17 | Workload /time necessary for obtaining pass mark |

## *C. Acceptance of the model*

When the cooperative learning model was implemented for the first time, the students' reaction was of suspicion and even some hostility (as reported by [19]). They appointed the increase of workload and responsibility associated with it, as well the nature of the groups' formation (most students were not willing to work with people they did not know well) as the main reasons for that behaviour. Later some conflicts within the group, different perspectives and ambitions for their marks, and difficulties in using and understanding the software were also identified. When the collaborative model was implemented the group formation was also a relevant issue for students. The use of the strategies referred before helped teams and individual students to overcome such conflicts. Although the workload was smaller, some students were not happy about it either and showed their discontentment. From the students' feedback, the major difficulty associated with the use of computing and software was using and understanding the software [7]. For some of them using English language was a real problem. For others, less familiarised with or with less aptitude for the use of computing, the necessity of using both was quite a challenge. In some cases these difficulties were not completely overcame. The specialised training on such issues helped. In the cooperative model, students with the same role in a specific project sometimes got together to work out how to use the numerical tools and overcome difficulties. In those cases a true specialists' team was formed.

### *D. Drawbacks*

In the cooperative model, some students tended to compartmentalize contents, reaching different maturity levels according to their role in each project. In some cases each team member was worried about fulfilling their own tasks, with no exchange of information within the team. In those cases a work review by the other team members was lacking. The main explanations relate to the way the coordinator faced his/her role, which in some cases led to a lack of team dialogue, a weak task planning and using all time available to complete tasks, not allowing the other team members to do an effective work review. Maintaining opportunities (practical lessons) where all students use hand calculations to solve problems, practicing all course contents, can help to minimise this. The final exam, where all contents are assessed, is essential for students to realise the level of understanding expected from them [14].

In the collaborative model such problem also occurred. However, as there were no established functions and the group had to organize its own work, some groups tended to solve all parts of the projects together, as a team, without dividing the work in several tasks. In some teams, students more used or comfortable with using computing and software were assigned by the team to carry out those tasks. Although this has increased the quality of their final project report, in many cases, it did not allow other team members to acquire the corresponding competences.

The impact of this teaching experience on the students' learning outcomes was quite varied. From the authors' experience and views, apparently for most students the group assignments helped achieving the overall learning outcomes stated for fundamental topics. However, their magnitude depends on the students and their learning styles, but, mostly, on their attitude towards their degree. They had to practice concepts using different approaches and perspectives and some also use their own spreadsheets to check the solutions of the given problems. Weaker or less motivated students, who just wanted to do the minimum to pass, limited to do their assigned task.

The intention was to have students creating their own spreadsheets from scratch (at least for the 1st project) and then progressively complete and correct them. Students had the responsibility of validating them, for example, using the problems solved by hand in practical lessons.

Some students tried to pass around spreadsheets. They asked information particularly from their senior colleagues who took the course in previous years. This could not be avoided and students that did it were the most affected. Their learning was compromised and they were not as prepared as their colleagues. In some cases students have confided the authors they tried that as a first approach. However, to understand their colleagues' work, to adapt the spreadsheet to the problem under study (different in each edition of the course) and to correct the mistakes they found was more difficult and time consuming than creating their own spreadsheet, thus most of them have abandoned such approach.

### *E. Further implications for students*

For some students these projects had a significant impact on how they faced Geotechnics [14]. Some were put away due to the amount of extra work they associated with the Soil Mechanics courses. Others really enjoyed it and even chose to prepare their M.Sc. thesis on Geotechnics. Students attending SMI or SMII with a cooperative learning model later, when preparing their M.Sc. thesis, showed a positive attitude towards the use of numerical tools and laboratory work and, simultaneously, fewer difficulties associated with the use of spreadsheets and text processors. What is more, the stress associated with the oral presentation of their work was smaller, even for shy and timid personalities.

As reported by [14], six students who successfully attended the cooperative learning models in SMI or SMII prepared their M.Sc. thesis in cooperation with a construction company. Such work was included in a national competition involving students from other universities and the prize was a paid 6 months' training period. The jury included technical staff from the company, the students' supervisors in the company, as well as external advisors. From the six students applying from UA (2010 and 2011) 5 were selected. In its 2011 edition, 3 (in a total of 4) winners were from the Civil Engineering programme at UA. The partners from the building company were positively surprised with both the quality of the students and their preparation to embrace professional work.

### *F. Lessons learned*

Implementing these teaching and learning models over the last years has enabled the authors' to develop a continuous reflexive process, which is helping to further develop them, becoming more efficient and effective.

The workload of the teachers increases significantly, related with both supporting the teams' work and marking a larger number of reports. Managing such workload and finding ways of adequately supporting students, giving them prompt feedback is essential for teachers attempting theses approaches. Some alternatives can include limiting the extension of the reports, which will also enable students to develop summarising skills.

Giving students prompt feedback is essential, allowing them to correct and improve their work, change their approach in the following projects and feel they are continuously supported by the teachers.

The success of these approaches depends essentially on the attitudes of students. Therefore, it is essential to convince them of its relevance for both their academic and professional success. The increased workload and the nature of the groups, though sometimes discomforting, better prepare students to face similar challenges in a professional life work environment.

The feedback from employers indicates these models have impact on students' employability and professional success. Assessing such impact and showing them to both employers and students can increase the employability of students and their commitment in the courses.

## V. CONCLUSIONS

The aim of the project-based learning models used was promoting active-learning by students, addressing different learning styles, adopting deeper approaches to subjects relevant for their professional or personal development, and advancing students to higher development levels. For that, mandatory open-ended team projects were used, which included the validation of numerical results through the application of theoretical solutions for the problems, as well as giving sustained estimates for values of certain quantities. The goals were to develop of problem solving and high order thinking skills, what was achieved. Several strategies have been used to assess the impact and the efficacy of these models (students' feedback; academic performance; and questionnaires at the end of the semester).

According to students' perceptions and to the overall judgement of the authors, the active learning strategies adopted were useful and successful in promoting and facilitating the construction of knowledge and in developing competencies by students. However the impact of the strategies adopted was not identical to all students. Their attitude and commitment are (as in any teaching and learning models) critical. Some students recognise their relevance during their academic path; others become aware of it when entering the professional life. Students are the key point of the learning process and if they are not willing or available to learn there can be no success.

Challenging students and making them realise they are the centre of the learning process can be disruptive. Some students enjoy and profit from such challenge, while others feel badly for being forced to leave their comfort zone. However, it is a rewarding process for all educators.

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