

Educational digital resource for data analysis of Soil Mechanics laboratory tests

Recurso digital educativo para el análisis de datos en un laboratorio de Mecánica de Suelo

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Abstract

This work aims to implement and evaluate an interactive educational software that helps Civil Engineering students to perform and analyze the calculations related to different Soil Mechanics laboratory tests. This experience consists of an attempt to incorporate information and communication technologies (ICTs) into the engineering teaching-learning process. The content of the program is distributed into three different modules: “Compaction test”, “Consolidation test”, and “Direct shear test”. Using vector graphics, tables, illustrative figures, animations, equations, tip buttons, and immediate correction of mistakes, the software clarifies the relationship between theoretical concepts and practical laboratory results, instructs the students in the moments of doubt, attracts their interest, and motivates them to achieve the complete data interpretation. Based on the results of an applied evaluation questionnaire, it was observed that most of the students were satisfied with the contents and functionalities of the program. The developed tool can be an inspiration for the creation of new educational software that improve the quality of education in different engineering areas.

El presente trabajo pretende implementar y evaluar un software educativo interactivo que ayuda a los estudiantes de ingeniería civil a realizar y analizar los cálculos relacionados con los diferentes ensayos de laboratorio de Mecánica de Suelos. Esta experiencia tiene como objetivo incorporar las Tecnologías de Información y Comunicación (TICs) en el proceso de enseñanza y aprendizaje de la ingeniería. El contenido del programa se distribuye en tres módulos diferentes: “Ensayo de compactación”, “Ensayo de consolidación” y “Ensayo de corte directo”. Usando gráficos vectoriales, tablas, figuras ilustrativas, animaciones, ecuaciones, botones de ayuda y corrección inmediata de errores, el software aclara la relación entre conceptos teóricos y resultados prácticos de laboratorio, instruye a los estudiantes en los momentos de duda, atrae su interés y motiva ellos para lograr la interpretación completa de datos. Con base en los resultados de un cuestionario de evaluación, se observó que la mayoría de los estudiantes quedaron satisfechos con los contenidos y las funcionalidades del programa. La herramienta desarrollada puede ser una inspiración para la creación de nuevos programas educativos que mejoren la calidad de la educación en diferentes áreas de la ingeniería.

Palabras clave: software educativo, Tecnologías de Información y Comunicación, Ingeniería Civil, Ensayos de laboratorio.

Keywords: Educational software, Information and Communication Technologies, Civil Engineering, Laboratory tests.

1. Introduction

Characterization of the soil is a fundamental step for the elaboration of any geotechnical project, since it allows the prediction of the soil's behavior under different load conditions. Some laboratory tests allow a better understanding of the soil. Through these tests, the engineer can deduce if it is suitable for geotechnical engineering purposes. The study of soil test procedures and the interpretation of the obtained results are current subjects in important classes of Civil Engineering courses, such as Soil Mechanics, Pavement Design, and Foundation Design. In many of these tests, a detailed calculation process is essential to correctly determine the desired soil parameters.

From the experience of teaching Soil Mechanics at the Federal University of Viçosa (UFV), Brazil, it was possible to notice that many students face great difficulties in adequately handling the numbers obtained in several laboratory tests taught in class. In order to contribute positively to the knowledge of future geotechnical engineers, this work developed an interactive digital resource that helps the students to treat and interpret data obtained from laboratory tests of compaction, consolidation and determination of the shear strength of the soil.

Yaman et al. (2015) point out that the latest Information and Communications Technology (ICT) have been successfully included to the conventional engineering education system. Many opportunities are changing the paradigms of the education models, such as remote and mobile learning. Based on their study, the authors verified that “the increase in the use of computers and the increased availability of software tools significantly affected the learning behaviors and expectations of engineering students”.

According to Maldague et al. (2016), ICT can improve the quality of education and provide many advantages to students and teachers. When teachers bring new technologies into the classroom, students feel more motivated to learn, exchange information more easily, develop creativity and self-regulated learning, and improve learning outcomes.

Milkova et al. (2016) cite the use of the artificial intelligence in education (AI-ED), in which intelligent softwares can be used in real education, in order to model human minds and bring many benefits to the educational process. The authors mention that intelligent tutoring systems (ITS) can “adjust its tutorial to the student's knowledge, to minimize their weaknesses and boost their strengths”.

The interactive educational software developed in this work is an attempt to incorporate the ICTs in the teaching of Civil Engineering and bring important innovations to the student's study of Soil Mechanics. It is specifically addressed to third-year students (primarily junior level) taking classes of Soil Mechanics I and II (CIV 332 and CIV 333). The software is able to assist the student in the development of the calculations necessary to determine physical and mechanical properties of the soil, based on the results of laboratory tests. From the numbers obtained in real tests or generated wisely by the software itself, the user is properly instructed throughout the calculation process necessary to obtain various soil properties. When using the tool, the students identify and correct their mistakes in the calculations routine or in the process of construction of soil compaction curves and stress-strain diagrams.

This software is part of a set of tools that have been developed by a research group of the Department of Civil Engineering at the UFV that seeks strategies that evidence the student as an active element in the teaching-learning process. Currently, the developed software is only available in Portuguese language and has been used only by Brazilian Civil Engineering students. The innovative ideas presented in the design and development of this software can be used to create interactive educational instruments applicable in different languages and different knowledge areas.

1.1. Literature Review

Technological innovations provide great opportunities for education. Gutiérrez et al. (2014) applied ICTs as educational tools to create a pedagogical approach whose main purpose was developing the Naval Engineering student's ability of analyzing and designing various kinds of ships. The authors describe the experience of using packages of the software Computational Fluid Dynamics (CFD) for numerical solution of fluid movement equations. Through questionnaires, it was possible to identify the students' high level of satisfaction with the application of the technological tools.

Mellado and Trechera (2014) developed interactive digital tools for the learning and teaching of Statistics in Engineering, which were adapted to each student. Personalized problems, exercises, and questionnaires were implemented for students who have similar difficulties in specific Statistics areas. The authors mention the use of HTML, JavaScript, Flash, LATEX, R, and GeoGebra to develop educational materials for virtual use in different learning contexts. These digital resources were evaluated by the students in a very positive way.

Other interesting applications of technologies in education are the Virtual Labs, computer programs that simulate sophisticated laboratory experiments, presenting the main features of a real laboratory. For example, Giménez et al. (2010) used Matlab GUI (Graphical User Interface) to develop a virtual laboratory for teaching the focusing properties of a directive lens. This tool was an effective way to motivate and help Engineering and Physics students to learn easily and quickly about a topic with wide range of scientific and technological phenomena.

Aranda et al. (2014) also state the effectiveness of virtual labs as a complement of traditional teaching methodologies. The authors describe the implementation of virtual labs related to three important Chemical Engineering unit operations: liquid-liquid extraction, distillation, and heat exchange. Questionnaires results showed that more than 85% of the students considered the digital tools of great utility in their learning process. The virtual labs also helped the students to improve different skills, like those related to teamwork, knowledge integration, critical reasoning, and the ability to analyze.

Adobe Flash Professional CS5 is a multimedia platform used to produce Internet applications, animations, and mobile games. ActionScript 3.0 is the programming language used in this platform. Coller et al. (2015) explain that once authored, the Flash presentation can be embedded as a `.swf` file. Then, the user can easily install a plug-in and play Flash movies in commonly used web browsers, such as Internet Explorer, Microsoft Edge or Mozilla Firefox. According to the authors, Flash "has become the most frequently installed plug-in: it is present in 98% of browsers".

Adobe Flash can be widely used in the teaching-learning process to create intelligent tutoring systems. For example, Nugraha (2017) used the Adobe Flash CS4 Professional platform to develop an interactive media that supports the thematic learning process. The media stimulated student's motivation and interest, and improved their Science test scores.

Rybalko (2016) proposes the teaching of mathematics through interactive multimedia tables and an electronic textbook designed by Adobe Flash means. The author points out that Adobe Flash technology is a powerful tool for creating and editing vector graphics, images, animations, sounds, and videos that can be used successfully in Math classes.

Walsh et al. (2011) developed an Adobe Flash based system for "simplifying the construction, use, and delivery of electronic educational materials in science". They state that these materials can be easily accessed via the Internet, using a computer that has the Adobe Flash Player plug-in installed.

Using Flash's ActionScript program codes, Gao et al. (2010) designed a collaborative learning environment for student's self-teaching that simulates the operation of targeted hydraulic circuits and equipment. The developed courseware module supports high interactivity and improves students' collaboration.

Within this context, this work aims to implement and evaluate an interactive educational software that helps Civil Engineering students to perform and analyze the calculations related to different Civil Engineering laboratory tests. The goal of the work is to use Adobe Flash functionalities to elaborate a tool that clarifies the relationship between Soil Mechanics theory and practice, instructs the students in the moments of doubt, attracts their interest, and motivates them to achieve the complete data interpretation. This experience consists of an attempt to incorporate ICTs into the engineering teaching-learning process, in order to help the students to understand important Soil Mechanics topics in which they face great difficulties.

2. The interactive digital resource

The interactive educational software was developed using the Adobe Flash Professional CS5 platform. The implementation process used the Action Script 3.0 object-oriented programming language. This section presents the main characteristics of the digital resource and their role in the achievement of the goals of this work. After being developed, the software was made available for download in a virtual learning environment commonly used in the CIV 332 and CIV 333 courses. A script explaining the program installation procedures was provided to the students. When some student had any issue, individualized assistance was provided. The content of the software is distributed into three modules. Each one of them helps the students to perform and analyze the calculations related to a different Soil Mechanics test. An interactive interface was carefully planned. It consists of two main areas: the central one, where the data obtained in the test and the results of calculations are exposed, and a lateral one, where the user is presented with some program instructions, tips, and equations to be used in each step of the calculation process. In the following items, the main characteristics of the software will be demonstrated in the different software's modules.

2.1. Module I: Compaction Test

According to Pinto (2011), soil compaction consists of the densification process of the soil through mechanical equipment, in order to increase the contact between grains and make it more homogeneous. By increasing the soil density, the compaction guarantees greater shear strength and lower permeability. The relationship between the soil's water content and dry density has been determined worldwide by the Proctor test. In this test, the soil can be compacted with three levels of Proctor energy: normal, intermediate, and modified. Thus, it is possible to construct the soil's compaction curves and identify, for a given applied energy, the optimal water content, for which the soil has maximum dry density. In Brazil, the test procedures are defined by the standard ABNT NBR 7182:1988.

When the user accesses the Module I of the interactive educational software, an explanatory text with information about the compaction test is presented in the central area of the screen. There, the student must choose the type of soil to be analyzed (clay, silt or sand). The program uses this information to simulate soil test results consistent with those obtained in real life. After that, tables with the test data appear on the main screen, which will be used by the student as initial parameters for the development of the calculation routine. Figure 1 shows the interface obtained through the described procedure. The calculation routine of this module

did not use any complex mathematical model, but only basic Soil Mechanics equations, such as those used to determine dry unit weight, water content, and other physical parameters of soils.

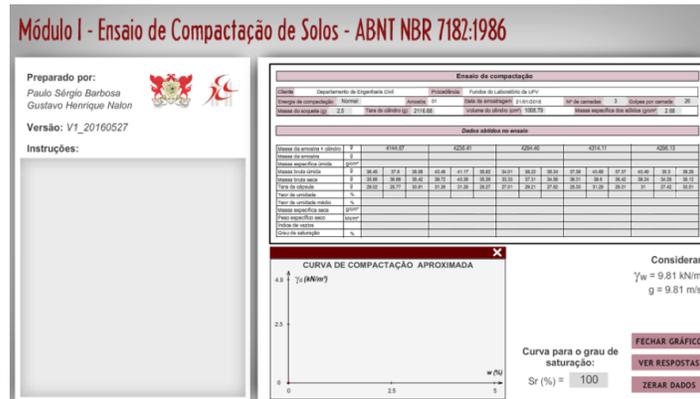


Figure 1: Central and lateral screen areas for the soil compaction test’s module.

The software intelligently generates random numbers to compose the typical data set of a soil compaction test. The program always preserves the consistency of the data, based on what is usually obtained in real laboratory tests. The generation of values considers the compaction curves of Brazilian soils presented by Pinto (2001) and reproduced in Figure 2. Thus, the optimum water content and the maximum dry density obtained at the end of the calculations will be in agreement with the expected values, according to the soil type selected on the home screen. Figure 2 also shows the approximate compaction curve obtained by the user at the end of the calculation routine, considering a sandy soil compaction test performed according to the Brazilian standard. If the students want to enter the data of a real compaction test, they can click on the “RESET” button and fill out the tables with their own values.

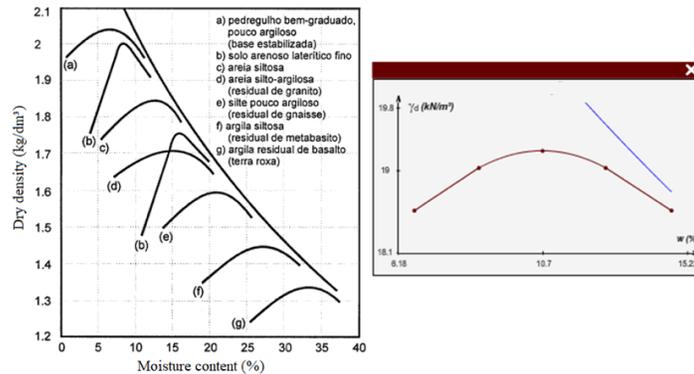


Figure 2: Compaction curves of Brazilian soils presented by Pinto (2001) and software’s compaction curve example.

By clicking on the top frame of the table in Figure 1, the user opens a General Data configuration window. In this window, it is possible to configure the test’s compaction energy and the dimensions of the Proctor cylinder. In addition, this window contains the specific gravity of soil solids, the weight and useful volume of the cylinder. Figure 3 shows the window that is opened when the user clicks on the frame related to one of the five determinations of soil’s water content and dry density. Gray cells are the ones that require the user to compute some parameter. When the user hover over the parameter name related to those cells, the instructions lateral area shows tips on how the calculation should be done. Once the calculation is done, the student types the answer and immediately knows if he has made a mistake or has been right. In

case of success, the cell turns green. In case of error, it turns red. The software further predicts and identifies any approximation and rounding performed by the user during the calculation of each parameter. For each correction, the program adopts a specific acceptable margin of error, which considers the parameter's order of magnitude.

Primeira determinação				
Massa da amostra + cilindro	g	4150.44		
Massa da amostra	g	2033.57		
Massa específica úmida	g/cm ³	2.02		
Massa bruta úmida	g	36.84	39.67	36.74
Massa bruta seca	g	36.28	39.03	36.15
Tara da cápsula	g	27.98	30.03	27.99
Teor de umidade	%	6.75	6.92	
Teor de umidade médio	%			
Massa específica seca	g/cm ³			
Peso específico seco	kN/m ³			
Índice de vazios				
Grau de saturação	%			

Figure 3: First determination of soil's water content and dry density.

2.2. Module II: Consolidation Test

Consolidation is a process in which the soil reduces in volume by decreasing its void ratio and water content over time. Experimental studies of the soil consolidation process allow the determination of its compressibility parameters and the prediction of the settlement due to primary consolidation over time. ABNT NBR 12007:1990 describes the test methods for determination of the soil consolidation properties when it is restrained laterally, drained axially, and subjected to successive load increments. The settlement is measured for each load level. With the test results, it is possible to plot consolidation curves of the soil. Despite the relationship between strains and stresses is not linear, it is considered the hypothesis that consolidation tests can estimate, at certain load levels, different soil parameters, such as the coefficient of consolidation, coefficients of compressibility, preconsolidation pressure, volumetric variation coefficient, and compression/recompression indexes, when applicable.

The developed educational software considers the theoretical model conventionally used to describe the consolidation process, which is based on the Terzaghi's one-dimensional consolidation equations. This model assumes the hypothesis that the soil is homogenous and saturated, soil particles and water are incompressible, flow of pore water is one-dimensional, relationship between strains and stresses is linear, Darcy's Law is valid and soil's properties remain constant during the process. Figure 4 shows the home screen of the Module II. To perform the consolidation test calculations, the student must have adequate prior knowledge about physical properties of soils. Whenever prior knowledge is required for the performance of a particular activity, the program provides the user with help buttons. In this case, the "PHYSICAL INDEXES" button gives access to a brief presentation about the definition of diverse soil physical properties.

In the first step of this module, the user needs to complete tables about the determination of the water content and general specimen characteristics. In addition to the help offered on

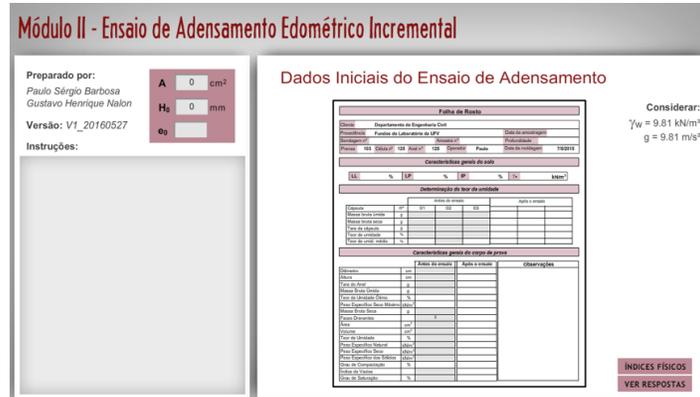


Figure 4: Home screen of the soil consolidation test’s module.

the lateral board, the user can also click on the “CHECK ANSWER” button at any time. When this button is pressed, the tables’ cells will display the correct value of the parameters that must be calculated in that step. Thus, the students have the possibility to correct their mistakes, based on the value that they were supposed to find.

In the Module II, the user must complete a table of calculation of soil compressibility parameters and construct the consolidation curve. In this table, the user needs to enter the values of the successive load increments and corresponding vertical displacements. As shown in Figure 5, eleven stage buttons are displayed next to the table. Clicking on these buttons, the user can obtain results of real consolidation tests performed in the UFV Geotechnical Laboratory. Alternatively, students can enter the data they have obtained in their own laboratory test.

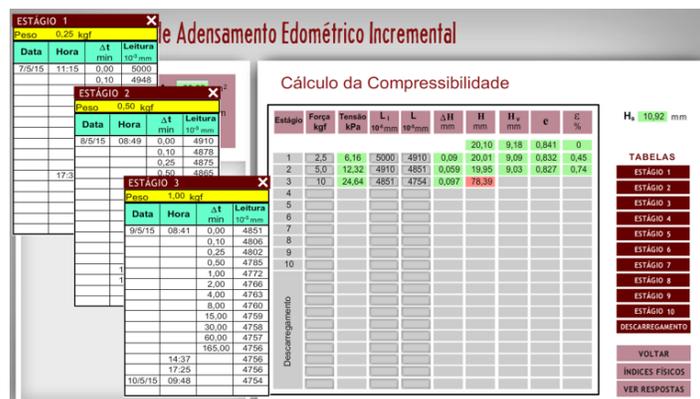


Figure 5: Tables with consolidation test data to calculate soil compressibility parameters.

2.3. Module III: Direct Shear Test

According to Das (2007), the shear strength of the soil is “the internal resistance per unit area that the soil mass can offer to resist failure and sliding along any plane inside”. One of the simplest methods used to determine the shear strength parameters of the soil is the direct shear test. For example, ASTM D6528: 2017 defines procedures for the direct simple shear testing of soils.

In the direct shear test, a soil sample is placed inside a shear box that has two stacked rings to hold the sample. A normal stress is applied to the specimen. After that, a lateral force is applied to the upper ring, until the sample fails. The horizontal and vertical displacements of

the ring are measured for each lateral load increment. The maximum supported shear stress must be calculated. The hypothesis that these procedures can provide the failure envelope of cohesive soils under undrained conditions was considered. Another assumption was that the shear area was constant when calculating the different levels of shear stresses. Furthermore, it was considered the hypothesis that under a given vertical pressure, the direction and the value of the normal load did not change.

The software developed in this work applies Mohr-Coulomb theory as the mathematical model used to describe the response of the soil sample to the normal and lateral loads. According to this theoretical model, the shear strength of the soil is expressed by Equation 1:

$$\tau = c + \sigma \sin(\Phi) \tag{1}$$

where: τ is the soil shear strength, c is the soil cohesion, σ is the normal stress, and Φ is the internal friction angle of the soil. The student can insert different values of normal loads. For every vertical load, the increments of lateral force and the horizontal and vertical displacements must be inserted. Applying the values of normal stresses and maximum shear stresses on the Mohr-Coulomb theoretical model, the user can define strength envelopes and determine the soil's cohesion and internal friction angle.

Figure 6 shows the shear stress-horizontal deformation and vertical deformation - horizontal deformation curves constructed by the user as he enters the calculated values from the test data. It is recommended that the student types the values in the order in which they were obtained during the shear test, in order to better visualize the curve construction process and the soil behavior throughout the test load stages.

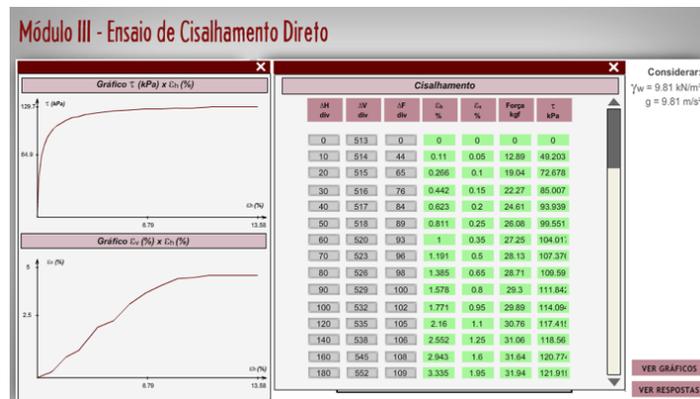


Figure 6: Graphical representation of the calculated values.

When using this software module, the user also needs to complete tables with characteristics of the test procedure, characteristics of the specimen, and force and displacement measurements. Various tips are available in each calculation step. The users are encouraged to look for help buttons, in order to access information that clarifies their doubts. For example, Figure 7 presents a tip consisting of instructive text, equation and animation of the direct shear test machine's movements. All of the program modules also feature these types of tips.

2.4. Software Evaluation

The interactive educational software developed has been widely used in the Soil Mechanics classes of the UFV Civil Engineering program. In order to know the opinion of the students about the tool, a questionnaire was applied to the students. The results were collected and

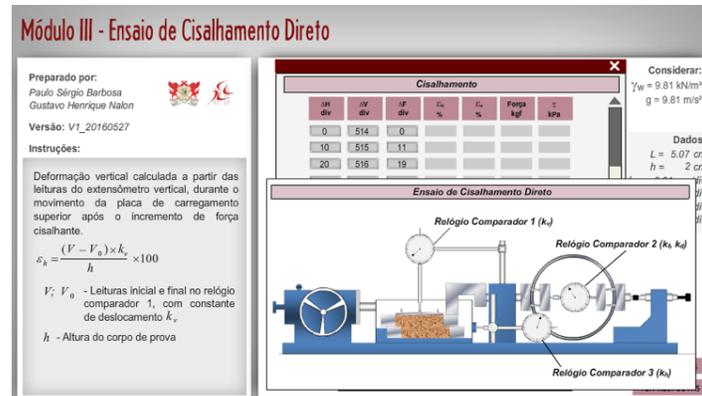


Figure 7: Valuable tips: instructive texts, equations and animations.

stored by a virtual forms system. Thirty students answered the questionnaire. Table 1 shows the evaluation results.

Criterion	Satisfied (%)	Dissatisfied (%)	Not applicable (%)
Adequacy to educational objectives	93	7	0
Adequacy to the course's syllabus content	100	0	0
Adequacy to the student's level of knowledge	97	3	0
Ease of finding useful information	93	7	0
Ease of use	100	0	0
Clarity of commands	100	0	0
Easy to read	97	3	0
Absence of errors	93	7	0
Number of explanatory texts and tips	97	3	0
Quality of texts and tips	97	3	0
Size of calculation routines	93	7	0
Quality of calculation routines	93	7	0
Enough information	100	0	0
Existence of motivational resources	97	3	0
Use of illustrative figures	90	7	3
Use of sound resources	87	3	10
Indication of successes and errors	100	0	0

Table 1: Interactive educational software evaluation.

According to the survey, all of the students were satisfied with the adequacy of the software to the course content, ease of use, clarity of commands, information quantity, and correction of errors. Criteria related to the content of the software were also very well evaluated. Most of the students were satisfied with the quantity and quality of texts, figures, calculations, and tips. A few students considered that the use of sounds and illustrative figures is not applicable. Then, it is suggested a better application of these kinds of content in the future development of similar digital tools.

In the questionnaire, it was also offered a space where the students could write their opinions about the software. Based on the answers of the students and discussions between students and professors, it was possible to realize that Adobe Flash provided the possibility of creating very helpful vector graphics, texts, animations, interactive tables, and buttons. According to the students, these tools attract their interest and help them to understand each step of calculation routines in a fast, specific and dynamic way. Students also point out that the interactive software

helped them to review important topics about the procedures and analysis of the laboratory tests. Then, they could better understand the relationship between the experimental results and the theoretical definitions related to the subject. In addition, the students also commented about the benefits of the immediate identification and correction of calculation mistakes. It avoids the inadequate understanding of each step of the calculation routine, and improves the quality and effectiveness of their individual study.

3. Conclusions

The development of teaching techniques that cover the use of information and communication technologies can provide a significant advance in the students' learning process. In this system, the teacher not only transmits knowledge, but also becomes a mediator of the teaching-learning procedures. The professor needs to understand the role of ICTs and develop new methodologies and educational resources. Students need to be enthusiastic to introduce new methods into their study routine and act as managers of their self-learning. Based on the results of the applied evaluation questionnaire, it was observed that most of the students were satisfied with the contents and functionalities of the developed interactive educational software. Student's opinions also indicate the main contributions of the software:

- Better understanding of the relationship between theory and practice: the digital tool offers tip buttons that allow access to texts and figures that elucidate correlations between theoretical aspects of Soil Mechanics and practical results obtained in the laboratory tests. The software also gives students the opportunity to constantly test different kinds of soils, which help them to understand the situations in which each equation or theoretical model is adequate. Furthermore, using the software functionalities, students can quickly modify soil's basic properties and easily realize how the changes affect compaction curves, consolidation parameters, and shear envelopes.
- Step-by-step instruction: the software proposes the problem situation, helps the student to use his knowledge to solve it, instructs him in the moments of doubt, and motivates him to achieve the complete interpretation of the results of each soil test.
- Motivation about the subject: the student is encouraged to look for information on the screen and learn more about what has doubt. He is also encouraged to persist in looking for the correct answer and to try to solve every step of the problem.
- Attractive visual language: Adobe Flash platform allowed the creation of vector graphics, tables, figures, and animations that attract students' interest and help them to understand the subject in a fast, intuitive, and dynamic way.
- Self-learning aid: the student becomes an active element in the teaching-learning process, building his own knowledge with the interactive content offered by the software.
- Immediate identification and correction of errors: the system quickly accuses the errors committed by students and improves their study productivity. In the instructions area, the students immediately find a way to correct their mistakes. They only advance in the development of the calculations after correcting the errors in the current step.

The elaborated software significantly helped the students in the interpretation of results of Soil Mechanics tests. This work proposed an efficient way of incorporating technological innovations into the traditional teaching-learning methods. The digital tool developed can be

an inspiration for the creation of new interactive educational software that improve the quality of education in various engineering areas.

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