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CONCEPTUAL FRAMEWORK FOR OPEN-ENDED LABORATORY IN GEOTECHNICAL LABORATORY COURSE

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Abstract:

The term "open-ended laboratory" (OEL) describes laboratory activities where each individual or group doing the activities will have a different final result. Not only does the end part vary as the openness scale rises, but so do the beginning and intermediate parts. The conceptual framework for OEL in the Geotechnical Laboratory course is provided in this article. The three levels of the laboratory work are OEL1, OEL2, and OEL3. OEL1 is simple to implement, however OEL2 and OEL3 require explanation in order to provide a summary of the differences between each level of OEL. In summary, it is critical to correctly execute OEL3 in the first year of study since it serves as the foundation for carrying out the final year project.

Keywords:

Open-Ended Laboratory, Geotechnical Laboratory, Level Of Openness

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Introduction

Laboratory work is one of the essential elements that must be included in the curriculum of any engineering program. Students will gain a deeper knowledge of the concepts presented in lectures through laboratory activities. In general, there are two types of laboratory work. Laboratory experiments carried out to confirm theories fall into the first category, whereas laboratory experiments carried out to look into other possibilities fall into the second. The latter group falls under the umbrella of Open-Ended Laboratory (OEL).

According to the Engineering Program Accreditation Standard (EAC, 2020), "It is expected that a significant number of laboratory works shall be open-ended". The phrase OEL refers to laboratory exercises in which students must design their own investigations. With an open-ended design, students must study both theoretically and practically (Priemer, 2006; Land, 2000) because there may be various solutions to the problem and no one optimum way to solve it. As a result, this increases the exploratory nature of the laboratory lesson by allowing students to utilize their own initiative and imagination to create original experiments (Planinšič, 2007; Chiu & Chiu, 2004). Because of OEL, students can enhance their capacity for learning (Berg et al., 2003), foster their own creativity, develop self-assurance (Gormally et al., 2009), and experience the real-world design environment outside of the classroom (Domin, 2007). OEL can also be considered similar to Problem-Based Learning (PBL), which had been implemented for quite a time. Learning using this approach aims to stimulate students to employ higher-order thinking skills such as applying and analyzing problems, evaluating decisions, and creating new ideas to solve issues (Zuki et al., 2024).

Because of this, open-ended working is currently used in the majority of laboratory work conducted in several scientific fields (Tsarpalis & Gorezi, 2005). Students are able to actively experience the emotions of working professionals because OEL are also connected to real student accomplishment (Wright, 1996). Berg et al. (2003) states that students who have weaker attitudes require greater support in order to tackle the challenge of OEL. This highlights the importance of students having strong self-motivation when it comes to OEL.

Previous study

Civil Engineering

Haron et al. (2013) conducted OEL using experiment on concrete design mix. The experiment concerning the concrete design mix is a mandatory component of most civil engineering laboratory courses. They found that the open-ended experiment fostered independent learning among students by providing them with an environment to showcase their innovation and creativity in creating and implementing their own experiments. The students acknowledge that OEL might enhance their preparation for the undergraduate final year project, foster innovative thinking, and simulate a genuine work environment. However, they found that the implementation of OEL required additional sessions for the experiment, as the regular in-lab session is inadequate.

Kukreti (2000) reported implementation of OEL in structural engineering field. Their students are involved in exploring the creation of a durable microconcrete with enhanced strength for use in miniature models, examine the performance of steel connections in low-rise building frames when subjected to seismic forces, and testing and evaluating modern seismic-resistant systems using reduced-scale models. They found that OEL effectively enhances students'

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abilities to plan and execute research projects with clear goals, fosters and stimulates participants' inquisitiveness and originality, and impresses both their peers and superiors with exceptional presentations and self-assurance.

A study on comparison between traditional (expository) and open-ended (problem-based) laboratory techniques in two cohorts studying environmental laboratory in civil engineering programs are performed by Bolong et al. (2014). The findings indicate improved performance and a 12% rise in course outcomes with the implementation of problem-based open-ended laboratory style. However, students' impressions of feedback are less positive.

Poor & Miller (2016) supervised OEL on hydrology experiment. Students are required to critically examine existing literature and formulate two testable inquiries based on two to three pertinent journal articles. Testable questions are inquiries that can be resolved by contrasting a specific situation or alteration to a control in a laboratory experiment. They found that the openness of the lab facilitated student ownership of their learning, and unstructured laboratory exercise was advantageous for student education and enhanced student comprehension.

Natural Sciences

Clement (1980) proposed a physics OEL, aiming to actively include students in the investigation of concepts such as force, displacement, velocity, acceleration, mass, and momentum. Students conducted experiment using three sets of apparatus: a ring stand, a flexible plastic track, and a metal cart. However, he only emphasized on qualitative observation, not quantitative measurement. Planinšič (2007) also implement OEL in physics laboratory, which consists of six projects for university level and three projects for higher professional level.

There is also OEL in field of chemistry, as implemented by Berg et al. (2003). They compare outcomes of open-inquiry and expository versions of a chemistry experiment, in order to determine if different outcomes depend on students' attitudes towards learning. The student was required to assess and contrast the efficiency and sensitivities of the enzyme catalase and the inorganic catalyst under various physical and chemical circumstances. Main findings from their study are: Open-inquiry version showed the most positive outcomes, and students with low attitudes needed more support, including clearer aims explanation and instructor feedback. A study by Domin (2007) include typical experiment in general chemistry curriculum, such as titrations, gas laws and Hess's law. He found that problem-based learning maximized conceptual development during laboratory activities, while expository learning maximized conceptual development outside of the laboratory after experiment completion.

Another work in natural science is done by Tsaparlis & Gorezi (2005), in the field of physical chemistry. They discovered that it is crucial to preserve the traditional element while enhancing it with a project-based element. Additionally, it was discovered that the laboratory technician exhibited a higher level of dedication, patience, and helpfulness compared to their typical behaviour. Priemer (2006) write on open-ended experiment about wind energy. Students can design a model of a wind energy plant and make decisions on the quantity, shape, dimensions, and orientation of the rotor blades. It was discovered that students had a preference for comprehending the context and rationale behind the utilisation of particular scientific approaches, even though they may feel overwhelmed. The findings are utilised by Priemer to

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create learner-centered assistance for student practical work with open-ended challenges, and adaptive feedback.

Other Engineering

Previous work on OEL in other field of engineering, are such as done by Rahman et al. (2011) in field of chemical engineering. Their study examines the differences between standard and open-ended laboratory work, with a specific focus on the outcomes of the programme. At first, students faced difficulties because they were not familiar with the assignment. The performance of students improved in the following semesters, which helped them prepare for their final year research projects.

Tranquillo (2006) report a study in field of biomedical engineering. Despite several challenges, there are lot of advantages for both students and instructor. Advantages for student are: students engage in multiple iterations of the design process prior to the senior capstone experience, students come to understand that the subjects covered in class are interconnected and students acquire problem-solving skills. Advantages for instructor are: individuals develop a deep understanding through direct participation in the lab design process, students often stimulate the creativity of the instructor and reading lab reports is a more pleasurable experience.

Chiu & Chiu (2004) describe a study in field of electronic engineering. They emphasise that among advantages of OEL are enhancement of students' comprehension and prepares students for the practical demands of the industrial sector. However, they noted several drawbacks, such as it is not suitable for first-year undergraduate laboratory due to the students' limited knowledge and standard laboratory session is inadequate for conducting experiments.

Based on previous work, it can be summarized that implementation of OEL will increase student understanding and experience in doing OEL is very useful for doing final year research project and later during work. Several drawbacks that had been observed are insufficient time to conduct laboratory work and unsuitable for first year students.

Scale Of Laboratory Openness

One of the pioneers in the development of inquiry-based science education was Schwab (1958). His aim was to bring laboratory activity closer to actual scientific experimentation. He distinguished between three inquiry science stages. In his first level, the teacher gave the class a problem to solve, and the students tried a variety of approaches. In the second level, the teacher gave the students an issue to solve, but this time, they had to come up with a solution on their own. Students had to propose a viable approach in addition to posing the problem at the third level of inquiry.

Later on, Herron (1971) expanded and improved this approach of inquiry. The Schwab-Herron Scale of Laboratory Openness was created by him. This was more inquisitive in nature and might be presented in a table. It illustrates what needs to be provided and done by whom in a laboratory exercise. Later, Tafoya et al. (1980) developed a straightforward technique of categorizing inquiries, presented in textual form. Table 1 shows both classification by Herron (1971) and Tafoya et al. (1980).

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Utilizing an inquiry matrix (Fradd et al., 2001) is a more sophisticated method of inquiry. This matrix divides the inquiry into more stages than the ones created by Herron and Schwab. The lesson is divided into multiple sections, ranging from questioning to applying, where decisions are made by the student or the teacher, as shown in Table 2.

Table 1: OEL Classification By Herron (1971) and Tafoya et al. (1980)

Level	Herron (1971)						Tafoya et al. (1980)
0	Problem	Given	Method	Given	Results	Given	Confirmation Exercises
1		Given		Given		Student	Structured
2		Given		Student		Student	Guided
3		Student		Student		Student	Open

Table 2: OEL Classification By Fradd et al. (2002)

Level	Questioning	Planning	Carrying out plan	Analyze Data	Draw Conclusions	Reporting	Applying
0	Teacher	Teacher	Teacher	Teacher	Teacher	Teacher	Teacher
1	Teacher	Teacher	Students/ Teacher	Teacher	Teacher	Students	Teacher
2	Teacher	Teacher	Students	Students/ Teacher	Students/ Teacher	Students	Teacher
3	Teacher	Students/ Teacher	Students	Students	Students	Students	Students
4	Students/ Teacher	Teacher	Students	Students	Students	Students	Students
5	Students	Teacher	Students	Students	Students	Students	Students

Implementation

In this article, the example of implementation is based on Geotechnical Laboratory course. The laboratory activities for this course are categorized as indicated in Table 3. The two degrees of openness for all laboratory activities in the curriculum are OEL1 and OEL2. OEL1 comprises of independently conducted laboratory work using a prescribed methodology. In contrast, OEL2 requires students to select a method. For instance, they have the option to undertake the Standard or Modified Compaction Test in Compaction and Field Density, and the Sand Replacement Test or Core Cutter Test in Field Density. They have three options for Light Dynamic Penetrometers: Mackintosh Probe, JKR Probe, and Dynamic Cone Penetrometer.

Students are provided a list of geotechnical parameters for the OEL3 level of openness, as indicated in Table 4. There are two groups for the parameters: physical and hydraulic/mechanical parameters. They must evaluate how physical attributes affect mechanical and hydraulic qualities. One physical parameter and one hydraulic/mechanical parameter will be selected by the student. After that, they have to formulate their own problem statement, which means they have to identify the issue that made the selected laboratory tasks necessary.

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Table 3: List Of Laboratory Works

Laboratory works	Level of openness
Moisture Content, Particle Density, Particle size distribution, Atterberg Limit, Constant & Falling Head, Direct Shear Box, Unconfined Compression, Unconsolidated Undrained Triaxial, Vane Shear, California Bearing Ratio (CBR), Oedometer	OEL1
Compaction and Field Density, Light Dynamic Penetrometer	OEL2

Following the formulation of the problem statement, the procedure is comparable to that of OEL2, meaning that they must select which laboratory test(s) to run, determine which variables are dependent and independent, select which data to gather, carry out the selected experiment, and then report the findings.

Table 4: Open-Ended Laboratory Level 3

Physical parameters	Hydraulic / Mechanical parameters
-density -water content -porosity / void ratio -degree of saturation -grading characteristic -liquid limit / plasticity index	-permeability -angle of friction -unconfined compressive strength -undrained shear strength -CBR value

The implementation of OEL3 in this course presents a number of challenges because it follows the syllabus, which stipulates that the list of required laboratory works is specified. However, it is also important to provide students the freedom to select the problem they wish to investigate and the laboratory works that will best help them do so. All of the laboratory exercises specified in the syllabus must be completed in order to use this implementation strategy, and the laboratory exercises for OEL3 will be selected from the previously completed exercises.

Figure 1 shows example of OEL3. In this example, student choose density as physical parameter and angle of friction as mechanical parameter. They need to establish problem statement; i.e. providing justification on the need to develop relationship between density and angle of friction. Following that, they must identify independent and dependent variable, and recognize laboratory test that need to be conducted.

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Problem Statement	**Current situation** Shear strength of sandy soil are determined via direct shear box test **What is the problem?** Difficulties to obtain undisturbed sample for sandy soil **What need to be done?** Estimate shear strength of sandy soil from density
Parameters	**Physical parameter** Density **Mechanical parameter** Angle of friction
Variable	**Independent variable** Density **Dependent variable** Angle of friction
Laboratory tests	**Density** Direct measurement of mass & volume **Angle of friction** Shear box test

Figure 1: Illustration of OEL3 Implementation in a Geotechnical Laboratory

Once the laboratory work had been completed, the raw data will be processed, and analysis will be performed to obtain required parameters. Following that, the relationship between density and angle of friction will be developed. In geotechnical engineering, many correlations between parameters had been proposed, so it might be necessary for students to compare their findings with previous works. As for this example, the comparison can be made with U.S. Navy (1982), as shown in Figure 2.

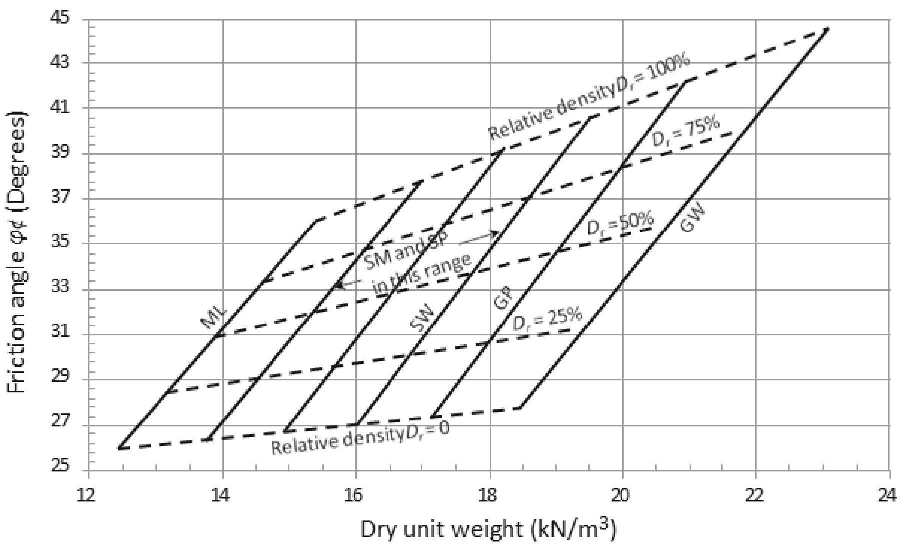

Figure 2: Angle Of Friction For Granular Soils, Based On Density (U.S. Navy, 1982)
Source: U.S. Navy (1982)

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The previously mentioned process is quite similar to final year research project, starting from problem statement until comparison of findings. This strategy provides an initial introduction to final year research projects for students, through the implementation of OEL3.

Conclusion

The conceptual framework for implementation of Open-Ended Laboratory (OEL) in Geotechnical Laboratory course had been presented in this article. Similar approach can be applied in other engineering course. It is essential to implement OEL in all engineering programmes, not only to meet the requirements set by the Engineering Accreditation Council, but also to adequately prepare students for their Final Year Project (particularly OEL3). The instructor must emphasise the significance of OEL3 for the Final Year Project. Despite several drawbacks, implementation of OEL3 will provide more benefits to both students and instructors or lecturers.

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