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Reinventing geotechnical engineering laboratory classes

M.B. Jaksa
School of Civil, Environmental and Mining Engineering, University of Adelaide, Australia

D.W. Airey
School of Civil Engineering, University of Sydney, Australia

J.K. Kodikara
Department of Civil Engineering, Monash University, Australia

M.A. Shahin
Department of Civil Engineering, Curtin University, Australia

S.T.S. Yuen
Department of Infrastructure Engineering, University of Melbourne, Australia

ABSTRACT: In his 1987 Nash Lecture, Prof. John Burland questioned the educational value of requiring undergraduate students to undertake routine laboratory testing, such as the triaxial, direct shear and oedometer tests. He stated that students are far from inspired by these. Other highly respected geotechnical engineering educators and researchers have expressed similar reservations about the current nature of geotechnical engineering laboratory classes. This paper re-examines the nature, structure and assessment of geotechnical laboratory experiments, explores their educational aims and proposes a framework whereby these classes can be more effective places of learning, be more engaging and more efficient. This last aspect is particularly challenging in recent times, as class sizes continue to grow to the point where educators are questioning the sustainability of resource-hungry and time-intensive laboratory classes.

1 INTRODUCTION

For quite some time, a number of eminent geotechnical engineering educators have questioned the value of undergraduate students conducting routine testing in the laboratory, such as the triaxial, direct shear and oedometer tests. Professor John Burland, in his 1987 Nash Lecture (Burland 1978) stated:

"*I have to admit to being somewhat ambivalent about undergraduate laboratory work. . . . I am at present of the opinion that routine laboratory testing, such as shear box, triaxial, and oedometer, is better demonstrated in class, perhaps by means of video recordings, using modern equipment and up-to-date testing procedures. The laboratory class would then be devoted to a few (perhaps two or three) experiments that are seen to be related to practical problems.*"

At the 1991 UK Meeting of Teachers of Geotechnical Subjects held at the University of Edinburgh, Orr (1992) reported "*Professor David Muir Wood . . . considered the role of laboratory testing and whether the aim should be to impart knowledge, skills or understanding. Laboratory testing is time consuming and [class] time is limited. He had no sympathy for the view that the manual recording and processing of data was good for students. Time needs to be spent productively and experiments which merely confirm well understood facts should be removed. Routine tests should be demonstrated, maybe by video, using modern equipment and up-to-date procedures.*"

Poulos (1994) supported this view stating:

"*Many existing courses appear to involve a significant amount of laboratory testing which is carried out by the students. However, with the advent of modern technology, it would seem desirable that, in the laboratory component of the basic courses, less emphasis be placed on the testing procedures themselves, and more emphasis be placed on demonstration experiments and tests which enable comparisons to be made with theoretical analyses.*"

Atkinson (2011) also strongly advocates that routine laboratory testing by undergraduate students is of limited educational value and his views align with those expressed above.

Despite these strong and consistent opinions from eminent geotechnical educators for almost three decades – and with which we agree – the vast majority of geotechnical engineering undergraduate courses include routine laboratory testing. Furthermore, there is a great scarcity of information available in the literature to enlighten teachers in relation to the most effective approaches and pedagogies to adopt when incorporating laboratory experiments in undergraduate geotechnical engineering courses. Notable exceptions are Airey (2008) and Airey et al. (2012).

All would agree that an experience in the laboratory by geotechnical engineering students is an essential part of their education. However, how should the laboratory experience be structured and designed, to maximise learning and student engagement, and how much time should be spent in the laboratory and what is the optimal use of resources needed to achieve these objectives?

This paper presents a model that is currently under development by the authors as part of a learning and teaching research grant funded by the Australian Government. The broad aim of the project is to develop a framework and an associated suite of traditional and e-learning resources to enhance student learning and engagement in geotechnical engineering laboratory classes. As mentioned above, an additional and fundamental criterion is to ensure that the framework and developed resources are designed in such a way as to ensure that laboratory classes are as efficient and, hence sustainable, as possible, without compromising student engagement and the learning outcomes.

Prior to discussing the proposed model, it is worth first examining the learning objectives associated with geotechnical engineering laboratory classes.

2 EDUCATIONAL AIMS

Are geotechnical laboratory classes relevant in today's engineering education? If so, what is unique about the laboratory experience that cannot be achieved in any other manner?

The authors believe that geotechnical engineering laboratory classes are relevant and are needed because they:

- Reinforce concepts that are treated in lectures;
- Allow students to compare experimental results with theory and allow one to challenge the assumptions that underlie much of soil mechanics theory;
- Allow students to observe the engineering behaviour of soil (and rock) in standard procedures;
- Develop experimental skills;
- Provide a sensory experience of soils, particularly tactile, and allow students to identify, classify and distinguish between different soil and rock types;
- Allow students to relate the experiment and results to applications in the real world;
- Allow students to deal with uncertainty (experimental error) and ambiguity; and
- Facilitate the interpretation of test data, particularly for design purposes, and communication of the test results to various audiences.

3 PROBLEMS WITH THE STATUS QUO

As highlighted by Profs. Burland, Muir Wood, Poulos and Atkinson, students are often uninspired by routine geotechnical laboratory tests. A key aspect of this is associated with the behaviour of fine-grained soils, where the time taken to obtain results is often not insignificant. This is particularly the case for oedometer and consolidated undrained triaxial tests on clay. These tests are slow and very little happens or can be observed and students cannot be easily engaged in these tests. The ability to speed up time in virtual tests is an attractive alternative for these tests.

Other factors that conspire to diminish student learning and engagement and add to the burden of scheduling geotechnical engineering laboratory classes include:

- *Increased class sizes*: The move from elite to mass education in the higher education sector over the last few decades, in most parts of the world, has resulted in ever-increasing class sizes. In Australia, it is not uncommon for academics to be teaching a geotechnical engineering course to more than 200 students, and in some institutions, the number is more than double this. Given the inflexibility of the teaching semester – around 12 to 13 weeks in Australia, all of the laboratory classes need to be scheduled within this period. The large classes and limited time available inevitably lead to students having to work in groups, sometimes with as many as 8 members. As many of the experiments have limited physical tasks that have to be performed, many students, particularly the reserved ones, simply observe their peers perform these tasks and disengage from effective learning. This is similar to the situation described by Burland (1987) at the beginning of the paper.
- *Increased pressures on the curriculum*: Laboratory sessions can occupy a significant portion of a student's timetable. This scheduled time is under pressure from external demands to increase the teaching of sustainability, climate change, environmental studies and soft skills training, such as technical report writing and presentation skills. These time pressures are leading curriculum managers to push for the reduction or even the elimination of laboratories, which also physically occupy valuable university space.
- *Expensive equipment requiring specialised technical support*: Geotechnical laboratory equipment is expensive and requires skilled technical staff to operate and maintain. Appropriately skilled technicians can be difficult to find. Because of space and personnel constraints, students are often forced to work in groups that are too large for effective participation.

4 PROPOSED FRAMEWORK

In order to optimise the amount of time spent in the laboratory and to enhance student engagement, it is proposed to adopt a framework incorporating three components, which are shown diagrammatically in Figure 1. The components include an introductory module, the laboratory session itself and a post-laboratory module.

The proposed framework suggests the use of e-learning tools in the pre- and post-laboratory modules and a streamlined laboratory experience. The three components of the framework are explained more fully in the following sections.

5 INTRODUCTORY MODULE

The first component is intended to introduce the students to the laboratory class so that the subsequent laboratory session can be more focussed, engaging and streamlined. It is proposed that the Introductory Module will be developed in the form of an interactive learning module (ILM) adopting e-learning authoring software such as *Articulate Presenter* (Articulate Global 2011a) as detailed in the companion paper (Jaksa 2012). The Introductory Module should include

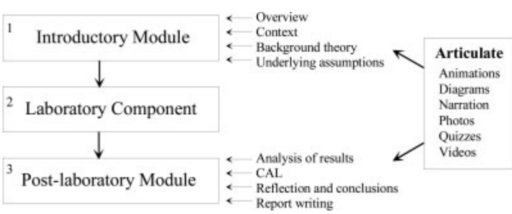

Figure 1. Proposed framework.

a list of the desired learning outcomes, the real-world context and applications which the experiment is relevant to, the background theoretical framework applicable to the experiment, embedded assumptions and the equipment and procedure that will be used in the laboratory component. It is intended that the module will be multimedia rich and incorporate video footage, animations and narration, so that it can be appealing and engaging. An example of an *Articulate*-based ILM developed in the form of an Introductory Module for the oedometer test is shown in Figure 2.

Importantly, the students' understanding of the concepts included in the module will be formatively assessed by means of quizzes embedded in the *Articulate* module. *Articulate Engage* (Articulate Global 2011b) will be used to develop these quizzes. It is not essential that the quizzes be used for formal assessment, rather as a tool to enhance the students' understanding. It is argued, however, by Airey et al. (2012) that some, albeit small, amount of summative assessment is critical to getting students to engage with the online modules.

The Introductory Module will be deployed to the universities' learning management system (LMS), such as *Blackboard* (Blackboard Inc. 2012) or *Moodle* (Moodle.org 2012), to enable students to access the material online, at a time to suit their convenience and at their own pace. The LMS will be able to track each student's access to the ILM and a condition of undertaking the laboratory component might (and ought to) be that they have taken the time to view the module and to answer the quiz questions. Whilst the introductory modules have yet to be developed, it is expected that, consistent with Airey et al. (2012), students will

Figure 2. Example of an introductory module developed in *Articulate*.

need to achieve a threshold score with respect to the quizzes, before being permitted to take the laboratory component.

Preliminary versions of introductory modules, however, were developed and implemented at the University of Adelaide in 2010. As outlined by Jaksa (2012), a survey conducted by the first author of 124 Level 2 geotechnical engineering students and 39 Level 3 students found that 84% and 85%, respectively, felt that the introductory modules assisted in the preparation of the laboratory classes and 73% and 82%, respectively, felt that they enhanced their learning.

In addition, as outlined by Airey et al. (2012), introductory modules of a somewhat different nature were introduced at the University of Sydney in 2010 and this resulted in a stark improvement in the students' engagement with the laboratory classes. For example, students who used the online resources gained higher average report marks (mean = 58.64) than those who did not (mean = 51.33).

6 LABORATORY COMPONENT

As mentioned earlier, traditional geotechnical engineering laboratory classes often involve students working in groups – sometimes as large as 8 or more – on a particular experiment, usually in a 2 or 3 hour session. The second component of the framework adopts a more streamlined laboratory class which is more focussed, requires less technical support, both in terms of preparatory work and supervision during the sessions themselves, reduced student contact time, and less demand on scarce equipment and laboratory resources.

In order to understand better the proposed approach, the example of the oedometer test is again explored. Traditional practice is to structure the laboratory session so that a student group undertakes the experiment, in essence, several times to develop a consolidation curve. Each point on the curve is obtained by applying a load to a soil specimen and recording the settlement over a period of around 30 minutes. Many clays often require a much longer period of time to consolidate and specially selected or amended clay is needed to achieve primary consolidation within 30 minutes. Usually, 6 to 8 points are needed to generate a representative consolidation curve. Hence, the time needed in the laboratory can be quite extensive and the measurement process itself is extremely dull and tedious.

An alternative approach is to reduce the time spent in the laboratory to approximately 45 minutes. This is achieved by the students measuring one point on the consolidation curve, rather than the entire 6. The complete set of 6 points is obtained by subsequent student groups, who each apply a different load and, hence, obtain a different point on the curve. Therefore, over a 3-hour period, the entire consolidation curve is generated. Subsequently, the students can access the complete set of data, again via the LMS, so that they can perform the relevant analyses, evaluate the required properties and write up the report.

At the University of Sydney another approach is adopted where thinner specimens (12 mm) are used, thereby reducing the time of consolidation. In addition, the student group completes an entire test with assistance of lab staff who apply and record the first three load increments. Elsewhere, sandy clays are used to reduce the time of consolidation.

Due to the streamlined laboratory component students spend less time in the laboratory, hence there is less pressure on timetabling and students can therefore work in groups of fewer students – typically, 3 to 4. The net result is a more efficient and sustainable laboratory experience, which is more engaging, as students participate in smaller groups and are better prepared. As a consequence, improved learning outcomes are expected to be achieved.

The project will also explore other approaches for the streamlined laboratory sessions in order to recommend a range of alternatives for academics to adopt to suit their institutions' needs.

7 POST-LABORATORY MODULE

Similar to the Introductory Module, the Post-Laboratory Module will again incorporate ILMs developed using the e-learning authoring software *Articulate* and will include content on compiling and understanding the data obtained in the laboratory, explaining the necessary analyses in order to quantify the relevant soil properties, a comparison of these properties with other soil types, treatment of experimental errors, and the requirements of the report and guidance on report writing.

An important feature of this third module is the inclusion of computer assisted learning (CAL) objects. Using these, in a virtual laboratory context, students will explore the influence of varying a number of parameters associated with the experiment in order to appreciate their influence on the soil properties under examination. For example, in the oedometer test, the soil type, permeability, coefficient of consolidation and drainage characteristics (i.e. one- and two-way drainage) can be varied to examine their influence on the time of consolidation and settlement. As a consequence of the incorporation of CAL, technical resources and repetition in the laboratory are minimised. The *CATIGE* learning objects (Jaksa & Kuo 2009) will be used for this purpose, an example of which is shown in Figure 3. The *CATIGE* objects will be developed further, particularly to make them more visually appealing so that they appear more like the real laboratory experience. As highlighted by Chang et al. (2011), today's students are far more demanding than previous students in terms of their expectations of the quality of the graphics and navigation of e-learning software.

In order to 'close the learning loop', the students will reflect on the learning objectives introduced in

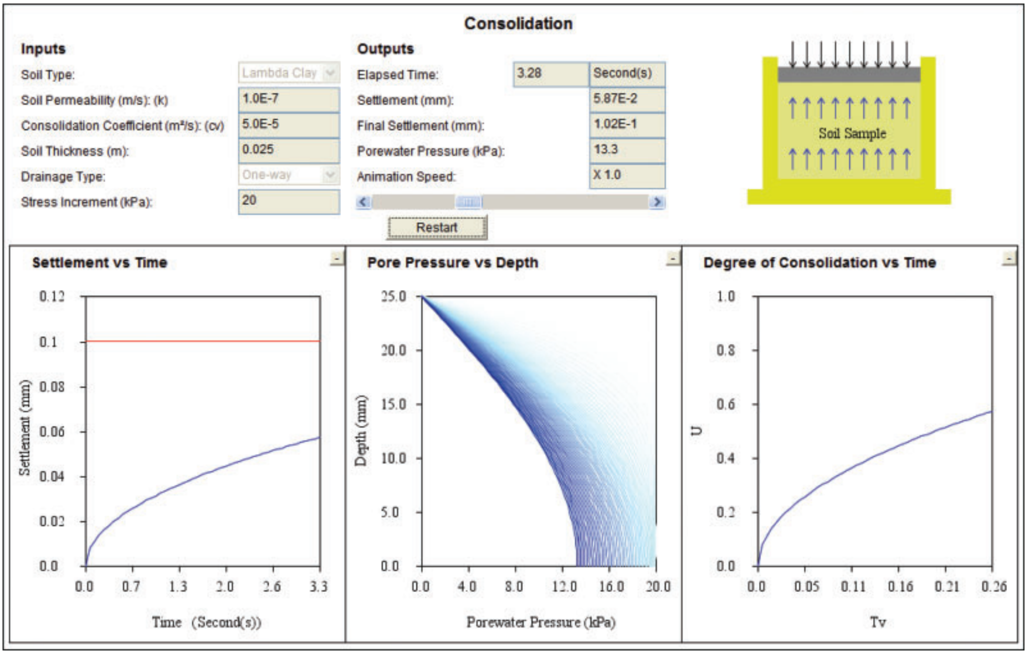

Figure 3. *CATIGE* – Consolidation object.

the first component and whether these have been achieved in the proposed framework by means of a quiz and survey. If the students' experience has been sub-optimal, they will be asked to provide feedback on how the experiment and its resources might be improved. This will provide a valuable ongoing resource for continued improvement.

8 PROPOSED EXPERIMENTS

The project proposes to develop traditional and e-learning resources for the following geotechnical engineering experiments:

- Soil classification – particle grain size distribution, hydrometer, Atterberg limits, field identification tests, linear shrinkage and moisture content test;
- Compaction – standard and modified tests;
- Direct shear test;
- Triaxial test – unconsolidated undrained (UU), consolidated undrained (CU);
- Oedometer test; and
- Seepage flow through an earth dam and beneath a retaining wall.

9 DISSEMINATION

A key aspect of the work outlined in this paper is to disseminate, as widely as possible, the resources that will be developed as part of this project, in order to facilitate its widest possible use. A web site is planned to be established as part of the work of TC306, the technical committee of the ISSMGE charged with geo-engineering education. Details of the TC306 web portal will be available via the ISSMGE web site and from the lead author. The resources will be freely available and will be developed in such a fashion as to provide as much flexibility as possible for academics to adapt the material to suit their needs.

In the interests of engaging as many academics as possible across the globe, comments and feedback on the proposed framework, experiments and resources are welcome. Interested readers are encouraged to participate and contribute to the project by sharing resources and by contacting the lead author (mark.jaksa@adelaide.edu.au).

10 CONCLUSIONS

The current nature of geotechnical engineering laboratory classes has been presented and several factors which diminish student learning and engagement have been explored. A framework has been proposed which incorporates three components – an introductory module, a streamlined laboratory experience and a post-laboratory module. The pre- and post-laboratory modules incorporate e-learning resources in the form of interactive learning modules with embedded quizzes and computer assisted learning objects to enhance student engagement and improve learning outcomes. An additional key criterion which is addressed by the framework is to ensure that laboratory classes remain viable and sustainable within an education sector with growing class sizes and greater efficiency demands. Initial work undertaken at the Universities of Adelaide and Sydney has demonstrated encouraging results, both in terms of improved learning and enhanced student engagement.

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REFERENCES

Airey D.W. 2008. A project based approach to teaching geotechnical engineering, *Proc. 1st Int. Conf. on Education and Training in Geo-Engineering Sciences, Constantza, Romania, 2–4 June,* 357–362.

Airey, D.W., Cafe P. & H. Drury, H. 2012. The use of online resources to support laboratory classes in soil mechanics, *Proc. Shaking the Foundations of Geo-engineering Education Conf., Galway, 4–6 July.*

Articulate Global 2011a. Convert PowerPoint to Flash with Articulate Presenter '09 (accessed January 2012). http://www.-articulate.com/products/presenter.php

Articulate Global 2011b. Articulate Quizmaker '09 – quiz software – create quizzes – survey maker (accessed January 2012). http://www.articulate.com/products/quizmaker.php

Atkinson, J. 2011. *Personal communication.*

Blackboard Inc. 2012. Blackboard – technology and solutions built for education (accessed January 2012). http://www.blackboard.com

Burland, J.B. 1987. Nash Lecture: The teaching of soil mechanics – a personal view, *Proc. 9th European Conference on Soil Mechanics and Foundation Engineering,Dublin, Ireland*, Balkema, Rotterdam, Vol. 3: 1427–1447.

Chang, R.L., Richardson, J.C., Banky, G.P., Coller, B.D., Jaksa, M.B., Lindsay, E.D. & Maier, H.R. 2011. Practitioner reflections on engineering students' engagement with e-learning, *Advances in Engineering Education* 2(3), 31 pp. http://advances.asee.org/vol02/issue03/06.cfm

Jaksa, M.B. 2012. Interactive learning modules in geotechnical engineering, *Proc. Shaking the Foundations of Geo-engineering Education Conf., Galway, 4–6 July.*

Jaksa, M.B., Ho, K. & Woodward, M.A. 2009. State of the art lecture 5: Management, training and education in geotechnical engineering, *Proc. 17th Int. Conf. on Soil Mechanics and Geotechnical Engineering, Alexandria, 5–9 October:* Vol. 4: 3136–3170.

Jaksa, M.B. & Kuo, Y.L. 2009. Java applets in geotechnical engineering, *Proc. 20th Australasian Assoc. for Eng-ineering Education Conf., Adelaide, 6–9 December:* 249–254. (On CD.)

Moodle.org 2012. Open-source community-based tools for learning (accessed January 2012). http://moodle.org

Orr, T.L.L. 1992. Innovations to inspire, *Ground Engineering*, May, 22–24.

Poulos, H.G. 1994. Patterns and practices in future geotechnical engineering education. *Proc. 13th Int. Conf. on Soil Mechanics and Foundation Engineering, New Delhi, India, 5–10 January, 1994*: Vol. 5, 245–253. New Delhi: Oxford & IBH Publishing Co.