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Engaging and Effective Laboratory Classes in Geotechnical Engineering

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SUMMARY: Most geotechnical engineering educators would agree that experience in the laboratory by geotechnical engineering students is an essential part of their university education. Traditional geotechnical engineering practical classes can, in the main, be described as unexciting, uninspiring and tedious. A key part of the problem is the loss of valuable contact hours in the laboratory waiting to observe modest response from the soil. Furthermore, often large group sizes, inadequate demonstrators' teaching skills and the absence of engaging study materials increase student disengagement and diminish learning. Student dissatisfaction with traditional laboratory classes has led many universities to question the educational efficacy of laboratory classes, particularly in a time of mass-education, and several universities have cancelled them altogether. This paper presents a framework and a series of resources, which have been developed specifically to increase student engagement and improve learning in geotechnical engineering laboratory classes. The framework consists of 3 components: (1) a pre-laboratory interactive learning module; (2) a streamlined laboratory component; and (3) a post-laboratory interactive learning module. At the core of each experiment are clearly defined learning objectives, which inform the structure of each module, the nature of the laboratory component and the assessment tasks. The first and third modules were developed using the *Articulate* e-learning authoring software, which provides a media-rich platform for developing engaging learning objects. In addition, a series of computer programs, collectively known as *CATIGE* (Computer Aided Teaching in Geotechnical Engineering), was developed and integrated into the post-laboratory modules and subsequent laboratory reports, to assist with the teaching of elementary geotechnical engineering principles to undergraduate students. The net result of this approach is a more efficient and sustainable laboratory experience, which is more engaging and, hence, achieves improved learning outcomes. The paper also discusses the development of the resources and reports the overwhelmingly positive student responses from the student evaluations. The developed resources are available online to geo-educators and students at no cost to facilitate their dissemination and wider use.

KEYWORDS: Laboratory class, e-learning, computer-aided learning.

1 INTRODUCTION

It is unfortunate that, while advances in our understanding of soil behaviour have vastly increased since the discipline of geotechnical engineering began formally to take shape at the beginning of the 20th century, in most educational institutions, little has changed in the teaching of geotechnical laboratory classes over the last 40 years or so. Although some academics have taken advantage of developments in computer-aided instruction and project-based learning to develop new and engaging materials (e.g. Elton 2001, Airey 2008, Jaksa 2008, Banky et al. 2011), these initiatives have been limited by resourcing issues and institutional inertia, and have not been widely adopted.

By and large, practical classes remain almost universally uninspiring, tedious and unfocused (Burland 1987). One can hardly describe the study of soil behaviour in the laboratory as enthralling. Adding to student disengagement and diminished learning is the fact that, because of increasing class sizes, limited laboratory resources and the fixed teaching periods, students often undertake laboratory classes in undesirably large groups. As many of the experiments require carrying out a limited number of physical tasks, many students, particularly reticent ones, simply observe their peers perform these tasks and disengage from effective learning. In addition, laboratory sessions can occupy a significant amount of a student's weekly contact schedule at a time when topics like sustainability, climate change, environmental studies and soft skills training, such as technical report writing and presentation skills, are being introduced into an already crowded curriculum. Time pressures are forcing the reduction or even the elimination of laboratory classes, which also occupy valuable physical space. Moreover, geotechnical laboratory equipment is expensive and requires skilled technical staff for its operation, and such staff are generally scarce.

Practical work in a laboratory class has been a characteristic of engineering programs for the very good reason that no other experience at the undergraduate or postgraduate levels can deliver the same learning outcomes for students. Laboratory work, ideally, should help motivate and stimulate student interest in the subject, while deepening their understanding of the essential knowledge and theoretical concepts of the subject. Laboratory work also provides opportunities for students to work together on analysing and solving engineering problems. Since working in teams and problem-solving are the most salient features of the engineering profession, the opportunities in the laboratory should be regarded by instructors as a vital opportunity to prepare young engineers, helping them to acquire behaviours and habits that will serve them throughout their professional lives.

The vast majority of geotechnical engineering educators and practitioners 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 details of a new framework and resources for delivering effective and engaging geotechnical laboratory classes. The paper also discusses the development of the resources, which are freely available online, and outcomes of student evaluations.

2 ADOPTED FRAMEWORK

The framework was originally proposed by the authors at the 2012 SFGE Conference in Galway (Jaksa et al. 2012) and it has subsequently been refined, developed and implemented. It consists of 3 components: (1) an introductory pre-laboratory interactive learning module (ILM); (2) a streamlined and focused laboratory component; and (3) a post-laboratory ILM. These are explained in detail in the following sub-sections. The adopted framework is summarised in Figure 1.

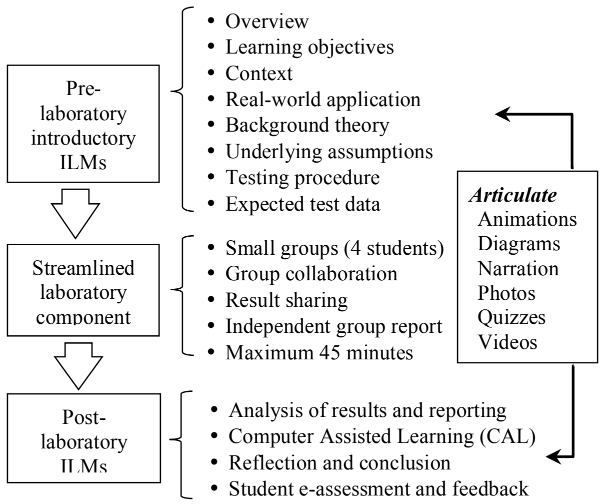

Figure 1. Adopted framework.

The design and evaluation of the framework and modules are informed by the work of Laurillard (2001), Garrison and Anderson (2003), Crisp (2007) and George et al. (2008). Laurillard (2001) advocates generating a teaching strategy which is discursive, adaptive, interactive and reflective; articulating clear statements of the learning objectives and designing the teaching materials and assessment tasks which closely align with the learning objectives; and including early evaluation which forms an integral part of the design process.

Garrison and Anderson (2003) suggest that learners are motivated by assessment activities and that one of the four characteristics of a quality learning environment is being 'assessment-centred', which implies ongoing, frequent and comprehensive formative assessment. Crisp (2007) provides an extensive overview of e-assessment, its validation and the use of Java applets. His work provides a sound basis for the development of the embedded e-assessment tasks.

To date, the following modules have been developed: (1) sieve analysis; (2) Atterberg limits; (3) hydrometer analysis; (4) soil compaction; (4) direct shear test; (5) triaxial test; (6) oedometer consolidation; and (7) flow through an earth dam.

2.1 Pre-laboratory interactive learning modules

This first component of the framework is intended to introduce students to the laboratory class so that the subsequent laboratory session can be more focused, engaging and streamlined. Recently, multimedia-rich software has become available – *Articulate* <www.articulate.com>, *Captivate* <www.adobe.com/Captivate> and *Raptivity* <www.raptivity.com> – which enables subject matter experts to generate e-learning objects rapidly from standard *Microsoft PowerPoint* files on their desktop. It also allows for audio and video narrated content to be packaged with interactive and feedback mechanisms, such as *Adobe Flash* <www.adobe.com/products/flash> interactions and quizzes (Carrington and Green 2007). This facility is particularly desirable given the universal nature of Flash content, and provides a quick and efficient means of creating, delivering and managing educational material. Maier (2008) argues that the use of such multimedia presentations increases student engagement and improves the student experience by providing an appropriate learning context and an active learning environment. The most recent version of *Articulate Studio* also ports output to HTML5 format.

An example of a learning object developed using the *Articulate* e-learning authoring software is shown in Figure 2. Such learning objects allow students to navigate the content freely and learn the topics in their own time.

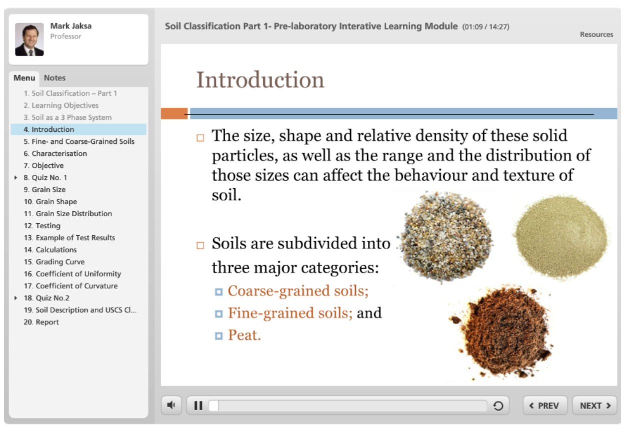

Figure 2. Example of pre-laboratory interactive learning module – sieve analysis.

This mode of learning is particularly relevant to international students, whose language skills may influence their learning ability in a traditional lecture or laboratory format.

The pre-laboratory ILMs consist of the following:

(a) a list of the learning objectives (Figure 3);
(b) introduction and background information, (which includes the real-world context and applications to which the experiment is relevant, some history related to the test and embedded assumptions);
(c) objectives of the test;
(d) sample preparation;
(e) laboratory equipment and operating procedures – described using video footage and narration (Figure 4);
(f) example test data, associated formulae and calculations (Figure 5);
(g) expected results;
(h) multiple quizzes; and
(i) report requirements.

Importantly, students' understanding of the concepts included in the module is formatively assessed by means of quizzes embedded in the ILMs. An example of the quizzes embedded in the modules is shown in Figure 6. *Articulate Quizmaker* was used to develop these quizzes. It is not intended that the quizzes will be used for formal assessment, but rather to facilitate students' understanding of key concepts.

Consistent with one of the main aims of e-learning, to enable students to access the material online at a convenient time and to facilitate learning at their own pace, the ILMs are designed to be deployed through the universities' learning management system (LMS), such as Blackboard or Moodle. An introductory module of this kind was introduced at the University of Sydney in 2010 and this

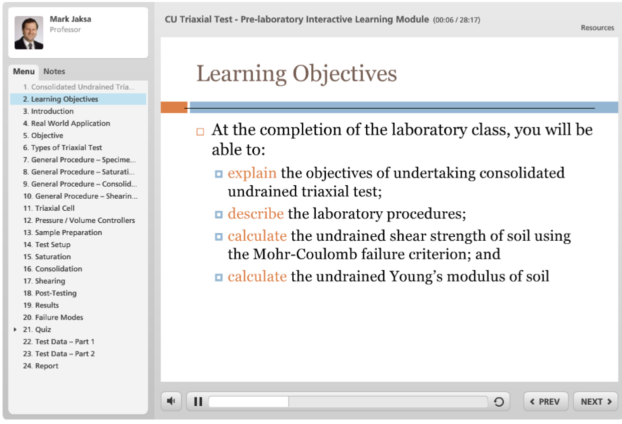

Figure 3. Learning objectives are clearly defined in each module.

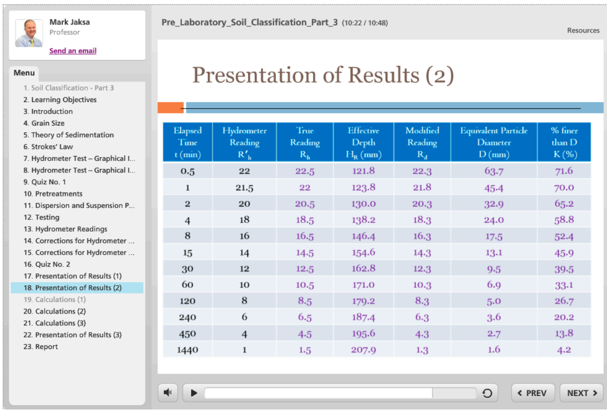

Figure 5. An example of hydrometer analysis test data and associated calculations.

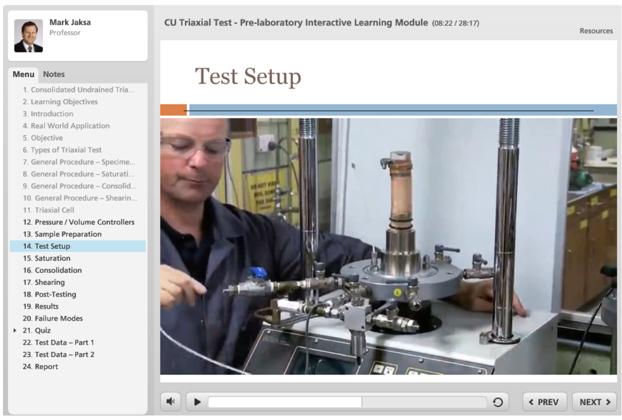

Figure 4. Video footage with narration explaining the setup of a triaxial test sample.

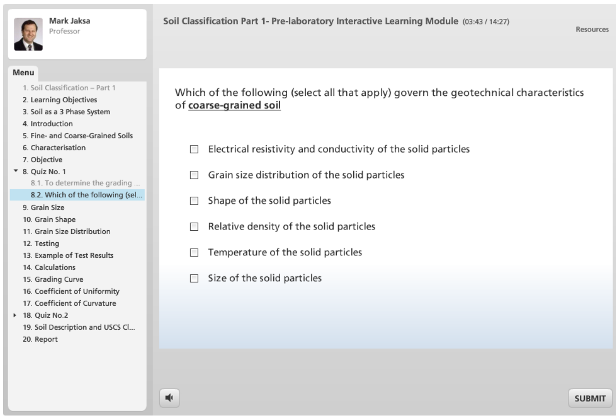

Figure 6. Quizzes embedded in the ILMs.

demonstrated a dramatic improvement in student engagement with lab classes.

2.2 Streamlined laboratory component

As alluded to earlier, traditional geotechnical engineering practical classes, at least until recently, have involved students working in groups, sometimes as large as 8 or more, on a particular experiment; usually in a 2 or 3 hour session. The framework proposes a more streamlined laboratory class which is more focused and requires less technical support, both in terms of preparatory work and supervision during the sessions, reduced student contact time, and less demand on scarce equipment and laboratory resources.

The oedometer test, for example, provides a better understanding of the proposed approach. Traditional practice often involves structuring the laboratory session so that a student group carries out the experiment, in essence, several times in order to achieve between 6 and 8 points on the consolidation curve. Each point on the curve takes between 15 and 30 minutes to obtain, and that us using a clay with added sand, or a thinner than usual sample thickness. Many clays often require a much longer period of time to consolidate fully. Hence, the time needed in the laboratory can be quite extensive and the measurement process is extremely dull, repetitive 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 or maybe 2 points on the consolidation curve, rather than the usual 6 or 8. The complete set of points is instead obtained by subsequent student groups, who each apply a different load and, hence, obtain a different point on the curve. Therefore, over a three-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.

The net result of this approach is a more efficient and sustainable laboratory experience, which is more engaging, and hence seeks to achieve improved learning outcomes.

An important additional benefit of this streamlined laboratory component is that, because students spend less time in the laboratory, there is less pressure on timetabling and, hence, students work in groups of far fewer individuals; typically 3 or 4.

2.3 Post-laboratory ILMs and computer assisted learning (CAL) objects

The main objective of the pre-laboratory ILMs is to prepare the students for the laboratory class. The aim of the post-laboratory ILMs, on the other hand, is to assist students in analysing and reporting the results, whilst reinforcing theory, as well as reaffirming the key learning objectives.

The post-laboratory ILMs have an important additional feature, which is the inclusion of computer-assisted learning (CAL). Since the early 1990s, CAL has provided learning resources additional to those traditional methods of instruction such as lectures, tutorials, textbooks, practical sessions and videos. CAL offers many advantages over traditional forms of learning, such as (Jaksa et al. 2000): (1) the ability to run simulations of laboratory experiments and design scenarios that allow the student to observe the effect on some behaviour by modifying various parameter(s); (2) the delivery of subject matter in an engaging and challenging manner; (3) students are able to learn at their own pace, rather than adhering to a schedule established by the course timetable; (4) student progress and areas of difficulty can be automatically monitored; and (5) scarce teacher, technician and equipment resources can be diverted to other areas, such as research.

Whilst CAL has a number of benefits, it also suffers from a number of limitations, such as (Jaksa et al. 2000): (1) if the CAL resources are poorly designed, the student may be more concerned with navigating or 'playing' the software than with learning; and (2) hardware limitations may cause the software to crash or the web-navigator to be unbearably slow, hence, detracting from the learning experience. As a consequence of these and other limitations, Davison (1996) suggested that CAL should not be seen as a replacement for traditional instructional methods. Rather, CAL offers an additional, powerful and engaging instructional, tool which enhances students' learning experience and outcomes.

Among the early developments of CAL, specifically for geotechnical engineering, were the significant UK *GeotechniCAL* suite of programs (Davison 1996), *Geotechnical Courseware* (Budhu 2006), *CATIGE* (Computer Aided Teaching in Geotechnical Engineering) (Jaksa et al. 1996), and the TU Delft Software and Resources (Verruijt 2006).

As part of the present work, the authors have improved and recoded the *CATIGE* software and it has been included in the post-laboratory ILMs. The *CATIGE* suite, incorporated in the ILMs, consists of a series of 5 computer programs written to model the laboratory experiments and improve the learning experience. The suite has been designed in such a way that users work interactively with the programs, and are required to provide numerical input. In this way, the students are involved in active learning. Inclusion of *CATIGE* into the ILMs enables parametric studies to be undertaken by varying a range of test parameters and soil characteristics so that students can appreciate their influence on soil behaviour in a more timely and efficient manner.

For the purposes of the present work, *CATIGE* has undergone extensive modifications and improvement with updated graphics to include a more engaging 'front-end', so that they more accurately replicate the real laboratory experience. To ensure that *CATIGE* will sustain, as best as possible, future technology cycles and the advent of alternate platforms and mobile devices, it has been reprogrammed in C#. CAL written in C# has opened the possibilities of cross-platform and mobile e-learning in the future, for example, e-learning using IOS and Android tablets. This approach will minimise the CAL's reliance on a single platform or operating system.

Another important change with respect to the CAL objects is to provide enhanced flexibility for instructors so they can create new soil types that are relevant to their specific regions and needs. In addition, these enhancements also permit the software to be translated into other languages, again increasing the relevance and reach of the project. These translations were achieved with the inclusion of a language file (text-editable .LNG file) in the application folder. The documentation for instructors has been developed to maximise the educational value and flexibility of the deployed resources.

An example of one of the objects (*Proctor*) is shown in Figure 7. The program, *Proctor*, demonstrates the standard compaction, as well as the modified compaction, tests. The user may choose one of *CATIGE*'s 6 hypothetical soils and the type of compaction test. The process is demonstrated by using an animated graphics screen. *Proctor* guides the student through the compaction test procedure and plots the results on a standard compaction graph. Students are able to add or remove moisture, as they would in the actual laboratory, and repeat the test, enabling several compaction points to be determined. Having done this, the user is then asked to estimate the optimum moisture content and the maximum dry density of the soil. The process is repeated again with different soil types. Students are able to compare the compaction curves for different soil types. As a consequence of the incorporation of *CATIGE*, the fundamental understanding of basic soil mechanics is enhanced, whilst optimising the use of limited technical resources and laboratory equipment.

3 STUDENT EVALUATION

Central to the development of effective pedagogies and learning resources is a strategy of regular, robust and independent evaluations and subsequent amendments informed by these evaluations. The evaluation of the framework and resources was informed by the Likert-scaled questions developed for Chemistry experiments by the APCELL project (George et al. 2008), which assessed students' learning skills and engagement. The evaluation also adopted the participant-oriented process proposed by Williams (2000), specifically for the evaluation of learning objects.

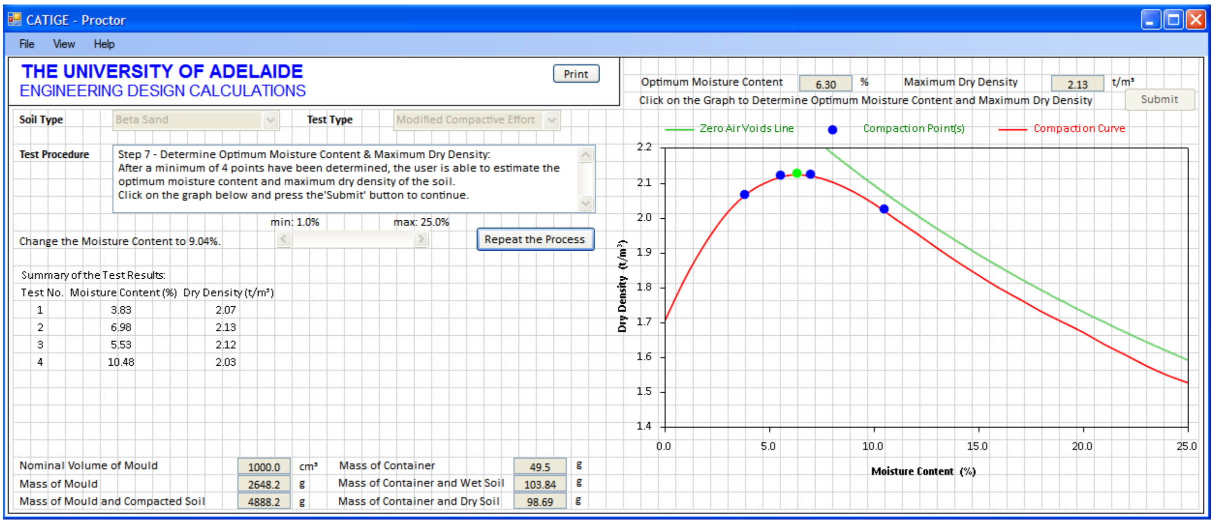

Figure 7. An example of a *CATIGE* learning object – *Proctor*.

In order to assess the efficacy of the framework and learning resources a student evaluation survey was undertaken by an external e-learning expert early in 2014. Students who undertook geotechnical engineering courses at Levels 2 and 3 in 2013 at the University of Adelaide were invited to undertake a pilot of pre- and post-laboratory ILMs for 4 geotechnical engineering experiments, along with a face-to-face laboratory component. The modules evaluated included sieve analysis, Atterberg limits, direct shear test and the Proctor compaction test. A total of 21 responses were gathered from the online survey.

In the survey, the learning objectives for both pre- and post-laboratory ILMs were surveyed in respect to the degree of student satisfaction, and a Likert scale [Strongly Agree (5), Agree (4), Neutral (3), Disagree (2) and Strongly Disagree (1)] ranking was adopted as the effectiveness benchmarking.

The key findings of the evaluation included:

- 60% of students found the pre-laboratory ILMs were the most effective component compared to the streamlined laboratory component and post-laboratory ILM, as elaborated by one of the students: "*By undertaking the module before the practical, students will have the benefit of understanding the real world application of the practical as well as being equipped to undertake the practical safely and efficiently. This helps reinforce the information learnt in lectures and will be very beneficial to those who use it as part of their learning.*"
- 80% of the students considered the videos to be the most effective aspect of the pre-laboratory ILMs and the practical experience to be the most effective part of the laboratory component;
- The diagrams were the most effective aspect of the post-laboratory ILMs; and
- All students agreed (45% strongly agreed, 55% agreed) that the pilot was an engaging, effective and efficient method of learning, and further comments indicated that they would prefer more of this type of learning.

In a separate survey undertaken at Curtin University involving 159 students, the following results were obtained:

- 91% of the students agreed that the ILMs assisted them in preparation and mastering the laboratory classes;
- 95% of the students found the ILMs helped them visualise what the lecturer and demonstrator were trying to convey and improved their understanding;
- 75% of the respondents acknowledged the use of the ILMs improved their engagement with the laboratory classes; and
- 89% agreed that the ILMs helped them perform better in the laboratory classes and enhanced their learning.

4 FINAL REMARKS

This paper has sought to effect meaningful transformation in geotechnical engineering laboratory classes. The framework proposed in 2012 and developed and implemented since, has, from a student perspective, improved student engagement and enhanced their learning. The framework also optimises scarce technical and equipment resources within constrained student and staff timetables.

In order to encourage the geotechnical engineering community – students, academics and practitioners – to adopt the framework, all of the resources, including *Articulate* ILMs, PowerPoint and video files, *CATIGE* software are freely available from:

<proxy.civeng.adelaide.edu.au/OLT/>.

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