A Study Evaluating Students' Long term Understanding of Effective Stress and Suggestions for its Improvement

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ABSTRACT: The effective stress principle is the crucible of soil mechanics; it controls all soil behaviours of interest to the geotechnical engineer. Since its formal postulation by Terzaghi in the 1920's, it has become core to every course in soil mechanics. Applying the effective stress principle in ground conditions that differ from the simple profiles presented when the subject is first introduced poses many difficulties for students. The simplicity of the principle means it can be covered in just a few pages of a textbook but this does little to promote understanding of the subtleties entwined in the principle. For example, issues such as the influence of static, flowing or capillary water on effective stress are rarely covered in a single location in textbooks, nor are these influences linked to the role they play in geotechnical design. This paper presents the findings of a study that evaluates the ability of undergraduate students to apply the effective stress principle in various geotechnical designs. Students in the study were taught the principle in an introductory soil mechanics module and their understanding was evaluated at the start of a follow-on soils module that commences after the summer recess. The results indicate that only a hazy recollection of effective stress remains and imply that careful attention to the teaching approaches employed are necessary if students are to retain their knowledge and proficiency in applying the effective stress principle in geotechnical design. Suggestions for enhancing learning in this area are provided.

Keywords: Effective stress, teaching and learning, soil mechanics, threshold concepts

1 Introduction

The effective stress principle is a core concept in soil mechanics that controls all soil behaviours of interest to the geotechnical engineer. It is essential that students clearly understand the principle and can apply it to any ground conditions encountered on site. To succeed in this endeavour it is necessary to specify the tasks we expect the students to be able to undertake after studying effective stress. In most undergraduate programmes the following skills are required:

1. Calculate total stress profile in a multi-strata ground profile including any applied loads from foundations or embankments.
2. Calculate the pore water pressure under hydrostatic conditions.
3. Calculate the effective stress under dry or hydrostatic ground water conditions.
4. Demonstrate by calculation the impact of a rising or falling water table on effective stress and hence explain why flooding has no impact on effective stress.
5. Calculate the effects of capillary water on effective stress and discuss why its beneficial effect is normally ignored in geotechnical design.
6. Calculate the effective stress in a ground profile when an upward or downward hydraulic gradient exists.
7. Determine the factor of safety against heave when excavations take place in fine-grained soil subject to artesian conditions.
8. Sketch the total stress, pore water and effective stress profiles for any of the above scenarios.

9. Discuss the implication of seepage forces on the geotechnical design of shallow foundations and show how the bearing capacity equation is modified to take account of upward seepage.
10. Discuss and illustrate the influence of soil permeability on the short and long-term stability of excavations when an upward hydraulic gradient exists.

The question arises, should all these skills be taught together or should some items be deferred until the relevant application is being covered in class. Time constraints in a semesterised system mean that some items on the list are often omitted or receive only cursory mention when effective stress is being taught. This coupled with ambitious syllabi generally result in what Gardner (1993) calls, 'the greatest enemy of understanding is coverage.' An incomplete understanding is the inevitable outcome when a lecturer attempts to deliver a dense syllabus within a 12 week teaching semester. The general approach taken at the University of Limerick (UL) is to teach through applied problems or triggers that carefully contextualise the learning within a given geotechnical application. A summary of how the geotechnical offerings are structured in UL's four-year undergraduate civil engineering programme is provided in Table 1.

Table 1. Details of fifteen-week undergraduate geotechnical modules at the University of Limerick

Module Code, Title & ECTS Credits	Task type & Hours/week		Year	Group based design trigger for Learning	Knowledge required to find a solution (Syllabus)
WT4014: Introduction to Geology and Soil Mechanics 6 ECTS Credits†	C*	2	2	Design a flood embankment to protect university buildings from the River Shannon bursting its banks.	1. Effective stress 2. Seepage 3. Compaction 4. Soil description and classification 5. Introductory site investigation – trial pitting
	E*	1			
	PBL*	2			
	IL*	5			
CE4015: Soil Mechanics 6 ECTS Credits†	C*	3	3	Design a suitable shallow foundation system for a multi-storey reinforced concrete building on a specific site (Part of an integrated design project – the structure and site change annually).	1. Shear strength 2. Bearing capacity 3. Elastic stress distribution due to loading 4. Settlement & consolidation 5. Soil structure interaction
	E*	1			
	PBL*	2			
	IL*	4			
CE4048: Geotechnical Engineering Design 6 ECTS Credits†	C*	3	4	Geotechnical design of piles, slopes and retaining structures using site-specific geotechnical reports.	1. Lateral earth pressures 2. Gravity and flexible retaining wall design 3. Slope stability 4. Pile design 5. Traditional and modern site investigation techniques.
	E*	-			
	PBL*	-			
	IL*	7			

*C: Class, E: Experimentation, PBL: Problem based learning tutorial, IL: Independent learning.

† 1 ECTS credit = 25 hours of student work.

The paper presents the findings of a short study that assesses how well undergraduate students understand the principle of effective stress having already studied it in an introductory soil mechanics module (WT4014). Four months after completing WT4014, the students are re-examined on the effective stress principle. In week one of module CE4015, students are informed that a comprehensive understanding of the effective stress principle is necessary for their project and are encouraged to review their prior knowledge on the principle in preparation for an end-of-week quiz. Their project involves the geotechnical design of a shallow foundation system to support a multi-storey building. The design criteria requires the foundations to be stable and that the total and differential settlements are tolerable. The quiz, which carries zero credit, involves ten conceptual and technical questions designed to elicit understanding of the principle and its application in various geotechnical design scenarios. Following this, four one-hour review classes involving the demonstration of effective stress calculations for a number of applications take place. The time allocated to these review classes is equivalent to approximately 10% of CE4015 class time. A second quiz with similar conceptual and technical questions is administered at the end of week three. Finally, after the results and feedback from both quizzes have been received, the students write a short reflection on their performance and understanding of effective stress. The second quiz and the reflective exercise are worth ten percent of the module grade. The review concludes with a tutorial involving a number of physical demonstrations (discussed later) which is designed to target the areas the students found challenging, this is delivered at the start of week 4.

Given its importance, the author believes it is worth investing the necessary time to apply the effective stress principle in various geotechnical applications. The review should take place at the expense of more procedural course content as these can be learned by reading a textbook and undertaking practice problems. For example, techniques for determining t_{50} and t_{90} from oedometer tests, secondary consolidation and settlement predictions in coarse-grained soils were omitted from CE4015 in this study to provide the time to review effective stress. Insights gained from this exercise along with the students' reflections are presented and suggestions for enhancing learning in this area are offered.

2 Challenges in Teaching Effective Stress

The effective stress principle is a threshold concept that students must master if they are to become good geotechnical engineers. Didau (2015, p160) quoting Meyer & Land (2003) defines a threshold concept as one where a learner crosses that liminal or in-between space of 'not knowing' and enters the space of knowing. Once this transition is made, the new material cannot be unlearned and it changes the way the learner sees the subject for the better. The focus of the teacher should therefore be to develop an integrated teaching approach that contextualises and unifies the geotechnical applications that involve determining effective stress.

The effective stress principle is so deceptively simple it tends to be presented in a 'matter-of-fact' way without significant discussion on how it controls the engineering behaviour of soil - at least this author has been guilty of such an approach. A review of a decade of examination results for WT4014 confirms effective stress is an 'arena of struggle' for young engineers. Over this time, results show the students obtaining little more than a passing grade on this essential topic. While a semesterised educational system presents obstacles to developing a deep understanding of the effective stress principle, there is a need to re-examine how the topic can be best taught within such constraints.

The author's experience suggests the students find determining the pore water pressure the more challenging component in the effective stress equation, probably because ground water conditions are highly variable. The following excerpt from Terzaghi's writings alludes to this '… in engineering practice, difficulties with soils are almost exclusively due not to the soils themselves but to the water contained in their voids. On a planet without any water, there would be no need for soil mechanics' (Goodman, 1999). The calculation of pore water pressures is a re-occurring conceptual and technical challenge for students that must be addressed before learning can take place. The following paragraphs outline the issues frequently encountered by the author:

2.1 Conceptual Challenges

- Students struggle to explain the effective stress principle in a way that indicates they have developed a clear understanding of its importance in geotechnical engineering. Table 2 shows a typical student response when asked to explain the principle. The question was initially asked after the summer holidays, some four months after the students were first introduced to the principle (Table 2(a)).

Table 2. Student response when asked to explain the effective stress principle

(a)	Quiz 1	$\boldsymbol{\sigma' = \sigma - u}$ Effective stress = total stress – pore water pressure. The strength of the soil taking the presence of water into account.
(b)	Quiz 2	The stress in the soil due to the friction between soil grains. If water is present in the soil, it has a buoyancy effect which decreases the effective stress.

Two weeks later and following some review classes, the answer to the same question is given in Table 2(b). Table 2(a) shows the memorised effective stress formula but no evidence that the student actually understands what is happening in the ground. There is only an incremental improvement in understanding evident in the second answer. Scrutinising tens of similar answers prompted the need to change how the topic is presented in this iteration of CE4015 and in future iterations of WT4014.

- Providing the conceptual framework that underpins the analytical formulation of the effective stress equation is also important. Some may deem this unwarranted, given σ' is not the actual grain-to-grain contact stress but rather the average stress over the loaded area. Nevertheless, the author has found the following rationalisation of the principle a useful learning aid for students. Considering Figure 1, the external force F applied to a confined saturated soil mass is shared between the inter-particle forces f and the pore water pressure u.

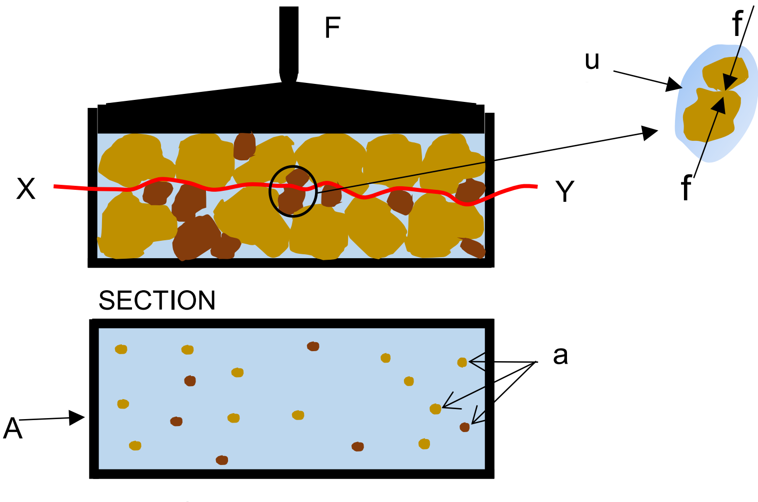


Figure 1. Conceptual derivation of the effective stress equation

In considering the vertical effective stress in the ground, we consider only the vertical components of these forces (f_v). We can write the vertical equilibrium equation representing the balance of forces across the wavy plane x-y, which is tangential to the grain contact points.

$$F = \sum f_v + u(A - \sum a)$$

'A' represents the total plan area of the plane and 'a' represents the average area of an individual grain-to-grain contact along the plane. Dividing both sides by 'A' gives

$$\frac{F}{A} = \frac{\sum f_v}{A} + \frac{u(A - \sum a)}{A}$$

We note F/A represents the total stress (σ) acting on X-Y and $\Sigma f_v/A$ represents the stress in the soil skeleton which is known as the effective stress (σ'). Rewriting the equation, we get

$$\sigma = \sigma' + u(1 - \frac{\sum a}{A})$$

The effective stress clearly depends on the value of $\sum a$ but since the inter-granular contact areas between soil grains are relatively small, $\frac{\sum a}{A}$ is negligible and can be ignored (Budhu, 2009; Knappett & Craig, 2012) and the above equation can thus be simplified to σ = σ' + u. It is helpful to emphasise that σ represents the external actions on the soil element being considered while (σ' + u) represents the internal response of the soil element to the external actions. As water cannot transfer shear stress, the stress induced by any applied loads must ultimately be resisted entirely by the soil skeleton through σ'. It is for this reason that the effective stress equation, in its truncated and approximate form, is normally presented as follows:

$$\sigma' = \sigma - u$$

- The occurrence of water in the ground is a useful starting point when setting the context for evaluating pore water pressures. The water table is defined as the location in the ground where the pore water pressure is zero. Below the water table, pore pressures are positive and thus reduce the effective stress. In fine-grained soils, surface tension effects cause the water to rise above the water table by capillary action. The capillary water causes suction or negative pore water pressure which results in an increase in effective stress. This enhanced effective stress is generally ignored in geotechnical design as an influx of water from rainfall or a rising water table causes the surface tension to breakdown as the pore pressures become positive; this phenomenon is clearly demonstrated in Burland's (2014) sandcastle experiments.
- Clear distinctions between pore water pressure and free water is essential, as this is often a source of confusion for the novice. Understanding that a full hydrostatic pressure can develop within very narrow interconnected void spaces (as is the case in most soils) is essential. This can be demonstrated by placing a transparent straw in a glass of water and noting that the vertical depth of water (h_w) in the straw corresponds to the depth of water in the glass (Figure 2a). If dry sand is then poured into the glass, displaced water will overflow but the depth of water in the straw remains the same (Figure 2b). The pore water pressure u at a given level is directly related to the depth of water according to $\gamma_w h_w$ where γ_w represents the unit weight of water and h_w is the height of water. The orientation (or shape) of the straw has no effect on u. Free water on the other hand is the water sitting in a glass (Figure 2a) or water located above the soil line (Figure 2c). In the case of Figure 2(c), the pore water pressure at the base of the glass remains the same as in (a) and (b) but we see the free water also contributes to the total stress at the base by an amount equal to $\gamma_w z_w$. The additional total stress from the free water is ultimately cancelled out when we calculate the effective stress i.e. $\sigma' = (\gamma_{sat} z_s + \gamma_w z_w) - \gamma_w (z_s + z_w)$ where γ_{sat} is the saturated unit weight of the soil. Thus the effective stress at the base of the glass in this case is equal to the submerged unit weight γ' of the soil multiplied by z_s, the depth of soil. This simple demonstration illustrates that free water above the soil line has no impact on effective stress and explains why the effective stress in soil say 1 m below a shallow river is the same as if the soil is located 1 m below a deep ocean.

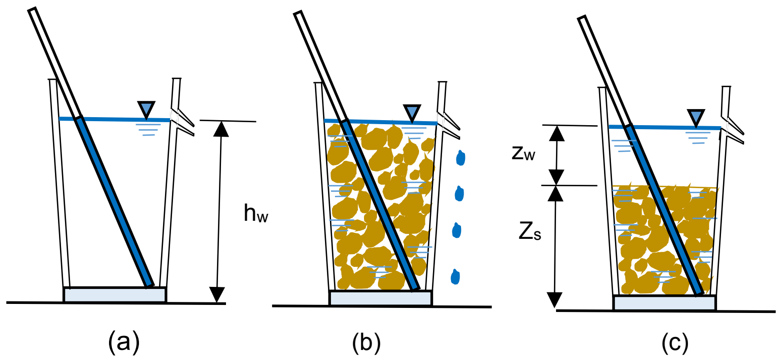


Figure 2. Conceptual representation of effective stress, pore pressures effects

- Ground water is rarely static. When it flows its impact on the magnitude of effective stress is significant. In coarse-grained soil, downward water flow increases effective stress and induces ground settlement but the more onerous condition is when seepage is upwards. Upward flow creates a frictional drag on the soil that opposes the self-weight of the soil grains and adds to the buoyancy effect thus decreasing further the force with which the soil particles press against each other. If the combined upward drag forces and the buoyancy forces exceed the soil's weight, the particles tend to lift off one another and the soil becomes a liquid mass with no strength.
- Conversely, when fine-grained soil is present, for example an alluvial flood plain overlying an aquifer, the pore water pressure may increase within the aquifer due to a rising water table or surface water entering the aquifer at an outcrop. The associated increase in pore water pressure in the aquifer is 'locked in' by the overlying low permeability stratum thus creating artesian

conditions. Construction under artesian conditions can present challenges such as those discussed in Section 2.2.1.

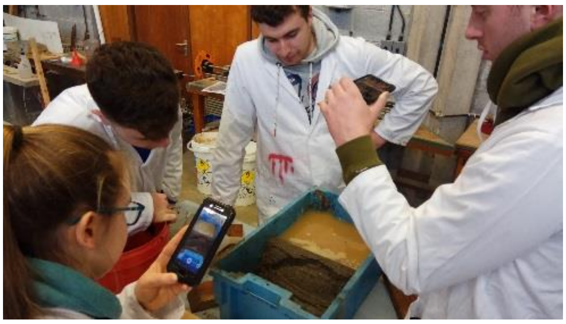
2.2 Technical Challenges

The response to loading in saturated fine and coarse-grained soils give rise to different short-term and long-term soil behaviours. Comprehending the nuanced differences between these conditions is essential when evaluating effective stress in seepage and strength calculations. Wesley (2019) suggests that identifying these differences on given sites proves troublesome for some engineers. These are discussed with the aid of teaching demonstrations in the following sections.

2.2.1 Stability and Pore Water Conditions

Base instability in excavations can be initiated by either a 'reverse' bearing capacity failure or a seepage failure. Focusing on failure due to seepage, two situations must be checked 1) a short term or base heave situation created by artesian pressures beneath a fine grained soil and 2) steady state seepage causing 'boiling' in excavations. Dealing with these can be challenging for students as textbooks do not often draw attention to these differences and when they do, the distinction is not normally discussed at the same location in the book. If both stability scenarios are not presented, students will be unaware of the checks that need to be undertaken to assess base stability when a hydraulic gradient exists within the ground. Ishibashi and Hazarika (2015 pp. 111-127) cover both situations in their book and Atkinson (2012, pp. 3-7) presents an interesting problem also covering both scenarios. Classroom demonstrations such as those illustrated in Figure 3 are helpful in enhancing understanding of seepage effects and these can also be used to predict the effective stress at failure if the soil properties are provided.

a) Building collapse due to upward seepage



b) Seepage failure in an earthen dam

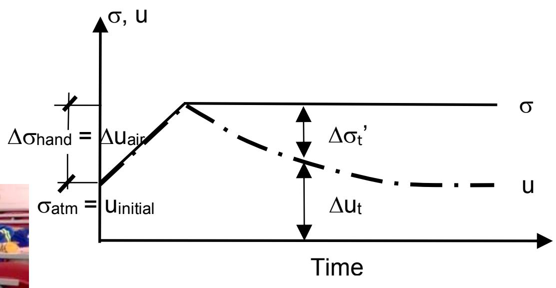
Figure 3. Simple classroom demonstrations to illustrate seepage effects on soil behaviour

2.2.2 Drained vs. Undrained Loading Conditions

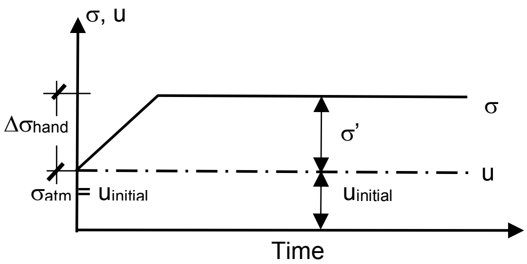
Identifying the drainage conditions in the ground is key to undertaking the correct geotechnical analysis. The conceptual background to assist in making this decision is provided in CE4015 via short online videos which the students are required to view ahead of class (Phillips, 2015 a & b). This approach is known as flipping the classroom and allows class time to focus on the material students find difficult. The magnitude of effective stress is influenced by the drainage conditions within the ground. A qualitative understanding of this can be obtained when each student undertakes the simple in-class experiment shown in Figure 4a. The permeability of coarse and fine-grained soil is simulated by varying the number of apertures created by a needle in bags of potato crisps; a large number of apertures represents the high permeability existing in a coarse-grained soil while a small number of apertures in a second bag represents the low permeability of a fine-grained soil. After the apertures are made, the initial air pressure inside each bag is equal to the atmospheric pressure i.e. $u_{initial} = \sigma_{atm.}$ If a load is then gradually applied by hand to each bag ($\Delta\sigma_{hand}$), the students can sense the rate of change in internal air pressure (Δu_{air}) as $\Delta\sigma_{hand}$ increases for each 'soil type.' The change in internal air pressure in each bag i.e. the pore pressure can be qualitatively sketched with respect to time for both scenarios as shown in

Figure 4b. From these plots, the students can extrapolate how the 'effective stress' changes over time as $\Delta\sigma_{hand}$ transfers to Δu_{air} and from this to effective stress through the potato chips (σ'_{chips}). Figure 4b(i) shows there is a delayed response in the transfer of Δu_{air} to σ'_{chips} in the bag having a small number of apertures. Significant time elapses before Δu_{air} dissipates to reach $u_{initial}$ and the audible 'crunch' of the 'crisp skeleton' is heard as it accepts the load through σ'_{chips}; this is analogous to the behaviour of a saturated fine-grained soil. Figure 4b(ii) illustrates the case for the bag with a large number of apertures. In this case, the time to 'crunch' is minimal since the air pressure remains at $u_{initial}$ and the applied load immediately transfers to the crisps as σ'_{chips}; this represents the rapid increase in effective stress experienced when coarse-grained soils are loaded.

(a) Classroom demonstration simulating drained and undrained behaviour using bags of potato crisps.



(i) Fine grained soil response.



(ii) Coarse grained soil response.

(b) Loading responses of fine and coarse grained soils.

Figure 4. Demonstrating influence of drainage conditions on effective stress

3 Change in Teaching Strategy

The effectiveness of students' learning depends on many factors including their interest in the subject, their maturity, their active engagement in class (by doing some task) and their attentive capacity while studying. With the exception of engagement, most of these factors are outside the control of the lecturer. What is within the lecturer's control is how the information is organised and presented.

Regardless of efforts made to meet students' learning preferences, time to assimilate new concepts is required and therefore it is argued that introductory soils modules should be built around the effective stress principle. A comprehensive treatment of this topic with adequate time for students to be assessed and receive feedback is an excellent investment in the development of a geotechnical engineer.

Measurement of learning is traditionally evaluated through heavily weighted end of semester examinations. These tend to focus on student performance rather than student learning. Continued use of this assessment tool encourages cramming information into short-term memory for recall in the examination. This knowledge is quickly forgotten as evidenced by the results discussed in Section 4. Therefore, a new model is required if students are to learn effectively, a model where retained information can be recalled and applied in new contexts. There is overwhelming evidence in the teaching and learning literature of the limited value of a traditional didactic lecture as a learning experience (Deci & Flaste, 1995; Prensky, 2001; Goodhew, 2010; Pink, 2010; Felder, 2012). Karpicke & Grimaldi (2012) and Didau (2015) suggest that a better approach is to teach a concept once followed by multiple assessments to embed and reinforce the concept. This approach along with the extensive use of technology and classroom demonstrations is adopted in this study.

4 Results of Quizzes and Discussion of Student Reflections

The quiz results are shown in Figure 5. The results from quiz 1 (n = 35) compared with the WT4014 results from similar end of semester exam questions revealed that an average class grade reduction of 50% took place over the summer period. The quiz 2 (n =32) results show a marked improvement on student performance. However, their knowledge remains 25% lower than the average pre-summer result in WT4014. It is disappointing that the quiz 2 results are not higher given the first four questions were identical to those in quiz 1. Questions 1 to 4 sought to elicit the students' conceptual understanding of effective stress by seeking explanations of the principle in their own words, the impact of artesian conditions on the stability of excavations and how the calculation of stability would differ if excavations were undertaken in i) coarse grained soil and ii) fine grained soil. The students struggled with such questions and produced regurgitated learned definitions with little evidence of understanding the physical implications of the effective stress equation on soil behaviour. Interestingly, the students exhibited less difficulty in calculating the magnitude of effective stress when the depth of static water varies in the ground including when it is above ground level. This suggests a certain parrot mentality towards the learning of soil mechanics. Questions calling for an awareness of short-term and long-term stability of excavations also posed problems. Students tended to perform stability calculations based on steady state hydraulic gradients despite the ground profile indicating the presence of fine-grained soil overlying an artesian basin – thus the need to check against base heave rather than piping. A marked improvement was noted in the end of semester exam. All students (n=37) attempted the questions involving effective stress. The results show the average class grade improving by over 200% on the quiz 1 result.

The improvement in the final exam is believed to be attributed to 1) a combination of time devoted to discussing and reflecting on how effective stress influences soil response under different rates of loading and ground water conditions and 2) on the 'teach once followed by test frequently' approach adopted in this study.

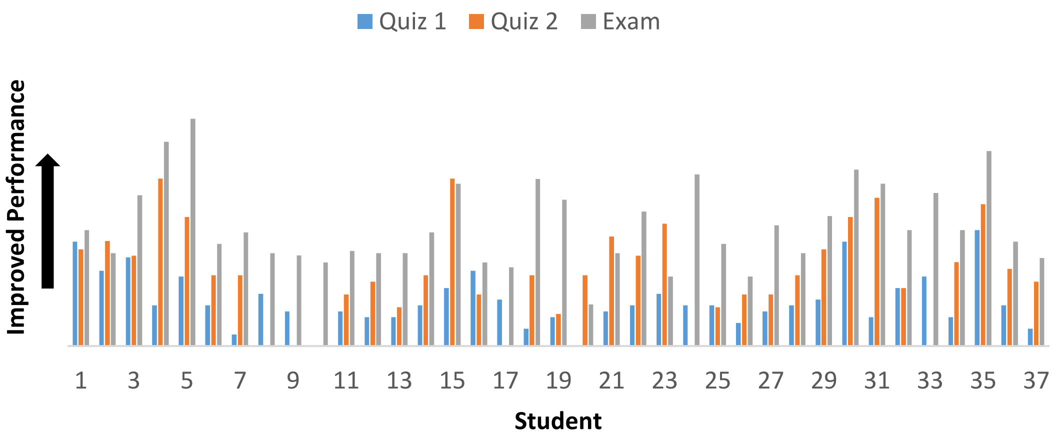


Figure 5. Results from tests on effective stress examinations

The following selection of reflections give a useful insight into the students' thoughts and perceptions. Students clearly realise that success can only be achieved through dedicated study but they also remind us that 'what gets measured is what gets done':

> 'The reason why I did so poorly in the effective stress quizzes is that I was convinced that I remembered enough of the topic from last semester. I feel that my understanding of effective stress has declined over the summer due to lack of practice and having not looked at effective stress in a few months I had forgotten a lot of the trickier bits.'

> 'My performance was poor in the first quiz due to my lack of preparation … I felt it wasn't worth the time, especially when it wasn't counted towards my final grade. My result went down in the second test, mainly because I wasn't prepared enough. I had missed a couple lectures prior to the test which didn't help. In the exam I knew that I should have known how to answer the questions which in turn frustrated me.'

The following comments highlight the importance of revisiting important concepts in class and providing timely feedback to assist learning:

> ‘ …. I thought these quizzes and the lectures spent reviewing effective stress were very useful as often when we complete an exam for a module the material is soon forgotten unless we are given a reason to think about it again. I also feel that it will be easier to further progress my knowledge of soil mechanics in this module now that I have a better understanding of the basic principles. I have also learned the importance of going over material several times in order to get a deeper understanding of it.’
>
> ‘I feel my understanding of effective stress did not improve after the quizzes but it has after the tutorial class we had today. Going through the quiz questions helped and showed how simply the questions can be answered when you understand what’s going on within the question.’
>
> ‘I feel the extra (post quiz) tutorial really improved my knowledge of effective stress. It made it more realistic and easier to understand as it was easy to visualise.’

The following quotations highlight the importance of drawing on prior knowledge to solve new problems. They also highlight the role played by careful and meaningful study to develop competence around effective stress:

> ‘The quizzes highlighted to me that just because something was done in a previous module doesn't mean I could forget about it as it won’t be needed again in further modules. While revising I realised I was just learning how to produce a certain answer for a certain question without fully understanding the problem. It was clear that I did not understand the question being asked and I was only just reproducing the same method for each question just hoping the numbers would fill in and I would get the correct answer. I found (the post-quiz) soils tutorial very helpful … It enabled me to get right back to the basics of what was being asked and leading to me being able to understand what was actually happening and being examined in the question.’
>
> ‘The main issue is how I study. I need to figure out a better system of actually absorbing information and then testing my own knowledge before I go into an exam. Staring at or simply reading over my lecture notes does not mean the information is going in.’
>
> ‘Quiz 1 made me aware that I did not have an understanding of effective stress… when asked to explain with sketches or in my own words, I did not have a good enough understanding to do so. The post quiz in class illustrations to describe what was occurring greatly developed my understanding of effective stress.’
>
> ‘This has been a beneficial learning process from a personal point of view. The two-quiz method is something that I have rarely completed in the past and having done so I can say it is a very good way to see can you improve as an individual and upon reflection I can clearly see simple mistakes I made in both quizzes but also how my knowledge and understanding has been developing.’

5 Conclusions

This paper has reported on the teaching of the effective stress principle to undergraduate civil engineers. In doing so, it has documented a number of obstacles and challenges to learning observed over the past decade. Demonstrations and teaching approaches that have proven effective in assisting the students understanding of the principle and their ability to apply it in different geotechnical design applications are presented. What becomes evident from the study and is reinforced by the students’ reflections is that learning only loosely correlates with what the teacher does but strongly correlates with what the student does. Nevertheless, the following useful insights emerge from the study:

- Undertaking effective stress calculations linked to construction scenarios contextualises the calculations within a design setting and promotes the development of a holistic understanding of the role effective stress plays in geotechnical practice. The process by which the student assimilates this understanding is fraught with challenges and it is certainly not a linear process as might be suggested by our carefully sequenced learning outcomes. It requires time and multiple repetitions before understanding is achieved.

- The 'teach once followed by numerous testing' approach has significantly improved the overall class understanding of effective stress. As a result, the introductory module, WT4014 will incorporate this teaching methodology in the future.
- Reflection in engineering education should be encouraged and should receive the same status as performing computational exercises. Without reflection, gaps in knowledge or poor study practices are not identified and corrected. To establish this status in the students' minds, course credit needs to be awarded for written reflective exercises. A mere suggestion that 'engaging in reflective practice is good for your professional development' is a poor motivator and is unlikely to spur the student into action. Once the habit has been formed and the benefits of reflecting garnered, the need for any incentive becomes obsolete.
- Many repetitions of the core concepts are required if they are to be etched into the brain's long-term memory. We must be prepared to devote the time required to achieve this goal even if this comes at the expense of a reduced syllabus.
- We must be mindful in our teaching to engage as many of the senses possible through use of classroom demonstrations, videos, clickers and in class activities that motivate students to learn.
- A student's decision to learn is entirely a personal one. Nothing the lecturer does can prevent a person willing to learn from doing so. The converse is also true, but the students willing to learn can certainly have their knowledge deepened and enriched through the adoption of student-centred pedagogies. Learners react positively when they are actively engaged by doing things in class and awarding credit for each assessment is generally effective in motivating engagement with the material.

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Declan Phillips is a senior lecturer at the University of Limerick (UL), Ireland. He spent five years in professional practice in the USA, specialising in geotechnical and structural engineering. He holds MSc and PhD degrees from the University of Dublin, is a registered professional engineer in the State of Pennsylvania and a Chartered Engineer in Ireland. Declan is responsible for designing UL's Problem Based Learning (PBL) programme in civil engineering which adopts a 'learning by doing' philosophy throughout the programme. He is a fellow of the American Society of Civil Engineers (ASCE) ExCEEd I & II programmes and is an Associate Editor for the ASCE Journal of Civil Engineering Education (formerly the Journal of Professional Issues in Engineering Education & Practice) and the Journal of Performance of Constructed Facilities. In 2008, he received a regional award for Teaching Excellence from the Shannon Consortium. He is a former member of the ISSMGE Technical Committee on Geo-Education (TC306) and was a member of the organising committee for the ISSMGE's international conference on Geo-engineering Education in 2012. Research interests include soil mechanics, instrumented field and laboratory testing, geoenvironmental aspects and reuse of municipal waste. He is also actively involved in research on student centred education and forensic engineering applications in teaching.