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Promoting active learning in geotechnical engineering

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ABSTRACT: With the frequent use of computer programs, young people nowadays generally lack independent thinking and judgment skills. This paper highlights the approaches that the author has implemented to promote active learning in geotechnical engineering modules. During lectures, only the key concepts of the topics will be presented. During tutorials, students from an active team will make presentations on an assigned topic followed by discussions and interactions by all students in the class. Although some students found difficulties in adopting in the beginning, majority of them later found the above approaches beneficial and started to reap the benefits of their own active learning.

1 INTRODUCTION

In October 2000, 150 engineering educators from 25 countries gathered at Aachen University to look at issues of educating the engineers for the 21st century (Weichert et al., 2001). The issues discussed included the role of global engineer in meeting the challenges of society in the 21st century, internationality and interdisciplinarity, developing personal scales to be a global engineer and other topics. In 2008, the American Society of Civil Engineers published a book on "The 21st Century engineer, a proposal for engineering education reform" (Galloway, 2008). On the other hand, specific issues on education in geotechnical engineering were discussed at the well-attended conference on Geotechnical Engineering Education and Training (Manoliu et al. 2000). It is evident that the issues of engineering education including those specifically in geotechnical engineering are now receiving more attention.

Nowadays most young people are familiar with the use of computers since junior/primary schools. They often run computer programs to obtain the results and prepare project reports with the aid of software. While the use of computer programs has many advantages such as very neat and organized presentations that can be easily amended and enhanced, young people often lack the necessary interpretation and judgment skills to make sound assessment of the computer outputs. They often blindly trust the results generated from computer programs without appropriate questioning and independent thinking.

The lack of independent judgment by university students affects the conduct of geotechnical engineering modules. As a subject, geotechnical engineering often requires students to exercise sound judgment to arrive at the most logical solution. As an example, students do not have a gut feeling on whether the computer output of proposing a 1-m wide stem for a cantilever reinforced concrete retaining wall is reasonable and practical or not. This is of course partly due to students' lack of practical experience. However, when they are questioned, they often reply that this is what the computer program has produced and believe that the computer outputs cannot be wrong. They often do not realize that if the wrong data had been inputted into the computer, the program would certainly produce incorrect answers.

In view of the above, the author has experimented with several approaches in the conduct of various geotechnical engineering modules at the National University of Singapore. Different approaches were implemented at various levels of undergraduate and graduate geotechnical modules. The aim is to promote active learning by the students. A good number of scholars had contributed ideas of active learning in the book "Research and practice of active learning in engineering education" (Graaff et al., 2005). This paper will present in detail three such approaches adopted. These include the use of actual field case studies to motivate students to think, the use of textbook rather than lecture notes in the conduct of junior geotechnical modules, and the adoption of active learning groups in tutorial classes. The students' responses to and feedback on the above approaches will also be discussed in this paper.

2 CASE STUDIES TO MOTIVATE THINKING

2.1 *Undergraduate modules*

In many universities, geotechnical engineering modules often start in Year 2 of the undergraduate civil engineering curriculum. Soil mechanics is typically the first geotechnical module covering basic soil properties, seepage and consolidation as well as shear strength. For a couple of years, this author had the opportunity to teach this Year 2 module and realized that many students found the topics of consolidation and shear strength very hard to absorb and a good number of them simply gave up.

Besides stressing on the fundamentals of the topics, the author would bring real life examples from Singapore projects to illustrate to the students why they have to learn these difficult topics. As an example, for the seepage topic, I highlighted the construction of the first underground railway tunnel under the Singapore River in the 1980's where sheet pile cofferdams were built to enable the construction of the cut-and-cover tunnels in dry conditions. Owing to the drawdown of water inside a cofferdam to facilitate dry construction, water seepage into the cofferdam needed to be determined. The concept of flow net and seepage was then gradually introduced. This is followed by the systematic discussions on the importance of various parameters such as permeability of soil and water head difference.

The author then highlighted to the students that the initial design had to be conservative to ensure no severe water seepage into the cofferdam during construction. With the actual field measurements obtained from the first cofferdam, the water seepage was found to be much smaller than the design estimation. The contractor was subsequently able to save cost and speed up the construction by combining the planned second and third cofferdams to a single cofferdam. With this illustrated example, the students realized that what they learnt was indeed practical rather than theoretical and became very interested in the topic. Of their own accord, a good number of them did further literature searches to learn more on the various practical applications of seepage theory.

Consolidation is another topic which students found hard to cope with. After explaining the concept and its applications in detail systematically and slowly, I gave them some real cases to think about. The Nicoll Highway incident (Ministry of Manpower, 2005) with the collapse of the retaining structure after 33 m of soil excavation in soft marine clay that occurred in Singapore in April 2004 was used an illustrative example. Towards the end of the consolidation topic coverage, students were asked to voluntarily submit their calculations on whether the 50-m thick soft marine clay has completed its consolidation settlement under a reclaimed sand fill placed about 50 years ago.

During the lecture, the author chose a couple of student submissions to present and illustrated to them that the thick soft clay was still consolidating. I further explained why the clay was still very soft and why a very deep excavation in thick soft clay could be problematic. Many students found this helpful to overcome the tedious and abstract topic of soil consolidation. More importantly I found a good number of students became very much interested in geotechnical engineering and no longer found the soil mechanics module very difficult and too theoretical.

Figure 1. Photograph of landslide and debris flow in Hong Kong.

Year 3 geotechnical engineering modules at the National University of Singapore covered the applied topics of slope stability, retaining structures, shallow and deep foundations. Some students who could not cope with the soil mechanics module in Year 2 were still quite lost with the Year 3 geotechnical modules. To motivate them to think on their own and enhance their interest, the author often presented actual field examples related to the topic covered from Singapore and overseas during lectures. I then encouraged them to take relevant related photographs inside and outside the campus when opportunities arise. They should submit the photographs with appropriate short discussions. In cases involving relatively complex topic which could be time consuming for the students, incentives such as bonus mark for course work were occasionally given.

Using an example from the slope stability topic, the author showed them slope instability cases worldwide. As an example, a debris flow slope failure from Hong Kong is shown to them during the lecture, see Figure 1. After explaining to the class the possible reasons for the slope failure and debris flow and their consequences, I informed the students that although Singapore has less steep terrains compared to other parts of the world; it still has many slope stability problems and presented them a slope failure example behind a house (Fig. 2) in Singapore which could be dangerous.

The author then challenged the students to look for warning signs of slope instability such as soil cracks and movements on slopes in Singapore. Some of them responded by sending me photographs they took on potentially unstable slopes. Figure 3 shows a photograph sent by a student on a Singapore slope showing signs of instability with cracks and observed soil movement. I then presented the student photographs to the class and highlighted to them that unlike buildings which must be absolutely safe; it can be difficult to ensure that all the slopes are safe in view of economics and practicality.

On the topic of retaining structures, the author highlighted to the students that they must know the concept

Figure 2. Photograph of landslide behind a house in Singapore.

Figure 3. Photograph of a potentially unstable slope taken by a student.

reasonably well and able to think beyond the topic. For example, I impressed upon them that it is important to know that a retaining wall design often involves slope stability check as a properly designed retaining wall may still fail if global slope stability check has been overlooked. That is why the topics of slope and retaining structures are often covered one after the other. In addition, the structural design of a cantilever reinforced concrete retaining wall, which students would be learning in structural design module, is also very important. Case histories had demonstrated that such retaining wall had failed structurally as the steel reinforcement was placed on the wrong parts of the wall stem. The above highlighted that students should be aware of the links among various components of civil engineering.

To further motivate students, the author urged them to take photographs of retaining walls within the campus and shared with the class. Using a photograph submitted by a student (Fig. 4), I illustrated to them the practical aspects of retaining wall design such as typical dimensions of wall stem and base of a cantilever reinforced concrete retaining wall. In addition, the provision of weep holes in retaining walls is very important in Singapore which often experiences heavy downpours. This would enable water gathered

Figure 4. Photograph of a reinforced concrete cantilever retaining wall in campus taken by a student.

Figure 5. Photograph of blocked weep holes on a retaining wall taken by a student.

behind the wall after rain to drain away as soon as possible to relieve the water pressure and hence loading on the wall.

To follow on the issue on weep holes, the author used another student photograph (Fig. 5) to illustrate that the weep holes provided in a retaining wall are often blocked by vegetation and hence maintenance of weep holes could be a major issue. An experienced engineer should not follow the book blindly believing that the weep holes would always function well and be able to drain the water behind a wall effectively. In Singapore, weep holes may be blocked by leaves after heavy rainfalls. Engineers should realize the possibility of water gathering behind a retaining wall could be a long term design issue and may need to check this condition as an extreme event. While full safety factor needs not be warranted in such extreme condition, a competent engineer should check that the wall is still marginally safe should there be water behind the wall.

With the above and other practical illustrate examples, the author reminded the students not to trust the computer outputs blindly and must learn to make correct judgment and interpretations. The ability to make

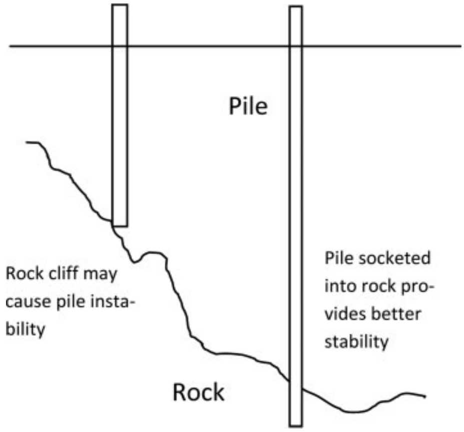

Figure 6. Practical problem in the field highlighted by a part time Master course student.

the right decision based on sound judgment would distinguish a competent engineer from a non-competent one. Hence I further explained to them that despite the many computer programs that are now available to handle complex calculations (some of them are so user friendly that technicians rather than engineers can handle the analysis), good competent engineers are still needed to make the right decisions.

2.2 *Graduate modules*

Many graduate geotechnical modules at the National University of Singapore are open to Ph D research students and master degree students by course work or research. Many of the master course work students are practising engineers and studying their master degree on part time basis. Final year undergraduate students are also allowed to take up to 3 graduate modules to enhance their knowledge in a specified field. Such mix of students poses some problems. The full time graduate research and final year undergraduate students do not have the relevant practical experience to appreciate advanced geotechnical topics such as ground improvement and deep excavations. On the other hand, the part time graduate students are mostly practicing engineers but many of them had forgotten the concept as they obtained their first degree sometime back.

To facilitate a better appreciation of practical problems, the author encouraged the part time students to share with the class the problems they encountered in their day-to-day work. Figure 6 shows a problem on pile installation provided by a part time student in the advanced pile foundation module. During the lecture, I used this example to illustrate the issues that engineers would face in practice and highlighted to the full time students that these issues are normally beyond the materials covered in the classes.

The author also showed the class a lot of photographs that I had been involved as a geotechnical consultant in pile foundation projects in Singapore and overseas. When presenting these cases, I also highlighted the theories and concepts that a practising engineer should possess when dealing with the problems. Both the full time and part time students appreciate this approach as they can benefit from each other. As the module is in progress, a number of full time students start to interact regularly with part time students to supplement each other. The full time students can now appreciate the practical issues faster after discussing with the part time students. On the other hand, the part time students are able to refresh and appreciate the concept and theory readily by interacting with the full time students.

3 LECTURE STYLE

3.1 *Textbook rather than lecture notes*

The recent trend of undergraduate civil engineering curricula is to adopt a broad-based training approach. As such, there are a large number of technical (for example geotechnical engineering), fundamental (mathematics and basic sciences) and humanity (for example human resource management) modules to be covered in an undergraduate course. However, technical modules are still expected to be taught to some depth in order to keep abreast with the latest technical development in a particular area. Hence undergraduate civil engineering students often face a highly crowded curriculum and have little time to appreciate the significant amount of course materials. As a result, students tend to adopt an 'optimal' learning approach to achieve the best grade with minimal effort and little time was spent to understand the fundamentals of the subject matter.

With a heavy curriculum, students often expect lecture notes to be given by the lecturer so that they need to spend the least time to study the subject. Unfortunately this poses problems for the conduct of geotechnical engineering modules. The author used to provide notes to the students. Although the student feedbacks generally revealed that my teaching has been clear and they appreciated I had spent time and efforts to explain difficult concepts, I found many of them still did not seem to be able to keep the concept and fundamentals after the module.

Despite seemingly doing well in their year 2 soil mechanics module, students are often unable to apply the concept learned in year 2 to year 3 geotechnical modules due to lack of basic understanding. To address this issue, I changed my teaching style about 15 years ago and no longer provided lecture notes to the students taking junior geotechnical modules. Instead I only covered the broad concept during lectures using standard soil mechanics texts such as Craig (2004) and Whitlow (2001).

In order not to overload the students, the author did not cover all the topics and mostly spent time on the key concept and fundamentals of the key topics. I informed the students that with the rapid development of new products and techniques, they will always need to learn how to handle new things on their own when they are working. As an example, the use of soil nails for slope stabilization is relatively new. The author highlighted to the students that their seniors 20 years ago would not have learnt this technique at university. However, many of their seniors were able to adopt such 'new' technique and design safely as long as they know the concept of slope stabilization well and able to appreciate the differences in the 'new' soil nail technique compared to traditional technique such as ground anchor.

Unfortunately for senior and graduate level modules, there are usually no suitable textbooks and the author had to provide lecture notes. Despite giving lecture notes, I always emphasised in class that understanding the concept and fundamentals is of utmost importance rather than solving the tutorial questions correctly numerically. A number of students always asked for sample solutions to tutorial examples to enhance their confidence in tackling the subject. This author did not oblige and highlighted to the whole class that in grading the assignment, quizzes and final examination, heavier weighting would be placed on answering the right concept related to the question than the accurate numerical outputs of the problem.

In addition, the author provided actual field problems from my research and consultancy projects. I highlighted to them many incidents and failures in the field were often due to mis-concept rather than calculation errors. As mentioned earlier, I also urged the part time master course work students to bring their site problems to the class for discussions. These field cases indeed raised the interests of many students and a number of them are highly motivated to be involved in the discussion of the field problems presented in the class.

3.2 *'Poser' questions*

As mentioned earlier, practical examples on real life problems were presented during my lectures to cultivate students' interest in the subject matter and to facilitate them to think deeper. In addition, the author often provided supplementary 'poser' questions related to the topic covered and encouraged them to submit inputs for discussions at the next lecture. The approach adopted is similar to the strategies proposed by Silberman (1996) on motivating students to be active right from the start.

The responses from the students are generally encouraging and their passion for the subject has been enhanced. During the next lecture, I would select some 'correct' and 'wrong' answers to present and highlighted to them that one can often learn from 'wrong' answers. The important thing is to get hold of the concept, learn the mistake and then move forward not to repeat the same mistake. I informed the students that making mistake can be a good learning exercise while repeating the same mistake illustrates that the student has just studied blindly and not learnt his/her lessons.

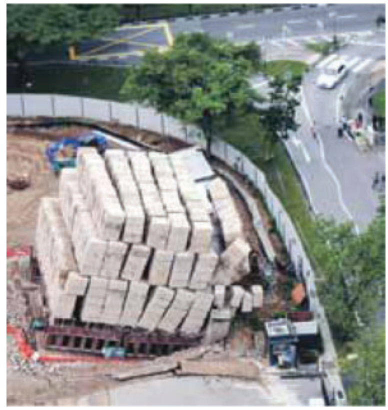

Figure 7. Photograph of failure of pile load test setup (Channel NewsAsia, 2010).

An important message the author passed onto the students is that they should be aware of errors in textbooks and even in design codes. I used the example of an error in BS8002 (1994) in which the incorrect hydraulic head on a retaining wall was presented, as discovered by British geotechnical engineers.

For fundamental topics such as retaining walls, I urged the students to report mistakes found in the textbooks so that I can share these with the class. When presenting the textbook errors spotted by the students, the author urged them to understand the basics and judged whether the mistakes are typos or concept problems.

For advanced geotechnical engineering topics, I highlighted to the students that the mistakes may be due to the state of knowledge at the time of writing and therefore they must be aware of the latest development when working in practice in the future. I illustrated to them how geotechnical theories advance over the years since the early days of Karl Terzaghi's soil mechanics theories.

Failure or near failure construction incidents happened from time to time and some of them are reported in the newspapers. When the incident is related to the module, the author presented them as 'poser' question during my lecture. In January 2010, a pile load test assembly failed during the course of a routine pile load test. The media Channel NewsAsia (2010) reported the incident online and a photograph of the incident is shown in Figure 7.

During the class the next day, I immediately urged the students to submit what they think of the incident so that I can share their thoughts with the class. The responses were overwhelming as the students felt highly motivated to have a chance to look at an actual incident related to the course and this only happens in a rare occasion. The subsequent presentation on student submissions was useful as the students were able to appreciate the incident deeper and I could see how they think as 'learner' civil engineers. I was unable to correct some students' mis-conception and the whole class appeared to appreciate it.

4 TUTORIAL STYLE

4.1 *Active learning team*

To encourage students to put in more efforts in a module, some faculty members adopt the 'continuous assessment' approach with a very high percentage of grading for the many quizzes and assignments. Students have no choice but to spend more times in order to obtain good grades. They often termed such module as 'continuous harassment' rather than 'continuous assessment'. As such, they often neglect other less demanding modules. As the curriculum is already heavy, it is simply not possible for the students to cope if all the modules have heavy continuous assessment components. In order not to overload the students, the author adopted 'active' and 'passive' groups during the tutorials in undergraduate geotechnical modules to lessen the students' workloads (Leung, 2002). Some of the strategies and techniques adopted are similar to those presented by Meyers and Jones (1993).

At National University of Singapore, undergraduate students attend common lectures in large lecture theatres and then divided into groups for their experiment and tutorial classes. Typically there are about 25 students in each tutorial group. Tutorial classes are generally problem-solving classes in which the tutors would present and discuss the solutions of the tutorial problems given in the lectures. Students then raise questions to clarify the solutions presented in the tutorials.

Many students do not attempt the tutorial questions before the class due to heavy workloads. They typically remain passive, often ask few questions and 'blindly' accept the solutions presented. As such, most of the tutorial classes do not achieve the purpose of mutual tutor-student interaction due to one-way transfer of knowledge from the faculty members to the students. The conduct of geotechnical tutorials is no different from other subjects.

To tackle the lack of interaction during tutorials, I developed the 'active learning team' tutorial method. To lighten the students' workloads, students from each tutorial group are divided into three teams. By rotation, one team would be assigned the active learning team for a tutorial class. A team leader was assigned and he/she played the role of coordinator by distributing the workloads among members and arranging the order of presentations.

The active team was only told to make a short PowerPoint presentation to highlight the key aspects of the discussion topic. Besides textbook and lecture notes (if available), students were free on how they approach the discussion topic. Many active learning teams were indeed innovative by referring to reference books, published papers and the World Wide Web. Active interactions and discussions among group members were strongly encouraged.

The active team members would make presentations followed by questions and discussions from the other two 'passive learning' teams. This enabled the active team members to acknowledge the view points of others and to understand the subject matter further after addressing the queries raised by fellow students. After the discussions, the active team would submit a short report to cover the essential and important points of the topic and distributed it to the whole class. In this way, all students in the tutorial group were able to learn without spending too much time and efforts on the large number of topics covered in the lectures.

4.2 *Interaction among groups*

As there are many discussion topics for each subject (for example slope stability), different topics will be given to the 8 tutorial groups. In general, four discussion topics will be given to the eight groups so that there is always a common topic between two groups to provide some competition as well as check and balance. As an example, the four discussion topics on slope stability include importance of shear strength of soil, effect of ground water table after slope excavation, vegetation on slope and the method of slope stability analysis. These topics represent a wide selection of important discussion topics in slope stability analysis that practising civil engineers should be aware of.

When the active learning team format was first put up, the students were skeptical and asked 'what is expected', or simply 'tell me what to do'. They were told they have a complete free hand and the process is entirely open-ended. They should always try their best to impress the faculty members and fellow students. The students were informed that their efforts would be rewarded as they and their fellow passive team members would learn a lot from each other in the process. After the first batch completed the active learning tutorials successfully, considerably fewer questions and concerns were raised in subsequent batches as they generally learned the ropes from their seniors following the style of their sample presentations and reports. Of course the discussion topics changed every year to ensure that each batch was able to learn on their own rather than copying from their seniors.

As Asians are generally less outspoken than Europeans or Americans, the author has to ask the first few questions during the first tutorial. I then continue to encourage the students to ask questions and persuading them that asking questions is often the best way of self-learning. After the students have more or less warmed up to the situation, they have no problems of raising queries such that subsequent questions and discussions become more lively and constructive. The active team students soon learn that they should look at a given problem from a wider angle or should have gone deeper on certain aspects of the discussion topic. At the beginning of the semester, the 45-minute tutorial typically finishes earlier. However toward the end of semester, it is not uncommon that the tutorial stretches beyond 45 minutes.

Upon feedback from the faculty member and passive team members, the active team is asked to prepare a short report for grading. The team leader is requested to report if any of his/her team members has not been active or never contributed to the process. Active teams who have made useful and interesting presentations are encouraged to post their PowerPoint files online to be appreciated by all students. The faculty member would review all the 8 tutorial group reports, made necessary modifications, fix the mistakes and highlight the important points in the reports.

Reports with serious technical errors would be returned to the students for re-submissions. If feasible, reports on the same discussion topics may be combined to provide a coherent and wider coverage of the discussion topic. These reports will be made available to all students who are informed that some of the materials will appear in the examinations. They are also encouraged to report mistakes in the submissions. Thus the students are able to appreciate the subject matter deeper. They very much appreciate it as they are better prepared for the quizzes and the final examination. Such a team work approach is elaborated in Kember (2000).

With the increase in the number of graduate students at the National University of Singapore, the undergraduate tutorial classes are now typically conducted by graduate students so that the faculty staff's teaching workload can be reduced. I continue to encourage the tutors to carry on the active learning team tutorial format to ensure good interactions during tutorial classes.

5 STUDENT FEEDBACK

At the National University of Singapore, student feedback is sought after all the lectures have been completed but prior to the final examination. This is to achieve fair and unbiased inputs by the students as the degree of difficulty of the final examination may affect the students' assessment of the modules and their lecturers. The student feedbacks basically consist of 2 parts: (a) quantitative inputs on a selection of questions on teaching and the module, and (b) qualitative inputs on the faculty member and module.

As with any new style of teaching, some students will find it difficult to adopt. For the first batch of implementing the above mentioned lecture and tutorial styles mentioned above, the qualitative scores were generally less favourable. A good number of students had unfavourable inputs such as 'the lecturer should be responsible by giving lecture notes and conduct tutorial properly by providing solutions to the tutorial questions.' Many students did provide constructive inputs on how to improve the process and some of their inputs were implemented by the author for the next batch.

With fine tuning of my lecture and tutorial styles, the numerical scores of teaching feedback in terms of both the faculty member and the module improved considerably. More heartening is that many students began to appreciate the teaching and tutorial style and reap the benefits of active and independent learning. In addition, many students had now overcome the fear of the basic soil mechanics module and became very much interested in geotechnical engineering. This is because they could relate the topics they learned to practice and hence developed a passion for the subject matter.

The success of the teaching and tutorial styles can be reflected in some of the student inputs. These included 'poses questions for us to think about and to let us learn independently'; 'able to understand the concepts better with his method of teaching'; 'encourage self-learning'; 'helped me understand how to apply knowledge and then has enhanced my ability to learn independently'; 'teaching philosophy to encourage self learning is essential to generate innovative thinking and ideas in engineering'; and 'fundamental concepts and understanding is the most important in learning'.

It is interesting to mention one particular case of feedback. During one tutorial, one student had totally forgotten that she has been assigned to be the leader of the active learning team of a particular tutorial class. Obviously the tutorial was a disaster for her and the whole class. After the class, the author then worked closely with the student and required her to upload her discussions and inputs on line to be shared and discussed by the whole class.

A couple of years later, I received a letter from the student who has since graduated thanking me for my help in her geotechnical modules. In fact, since I pushed her to do the tutorials, she became very much interested in the subject and scored well in the geotechnical modules. Because of this, the student had chosen to work as a geotechnical engineer.

6 CONCLUDING REMARKS

With the frequent use of computer programs, many young people are unable to grasp concepts and fundamentals well. This affects the conduct of geotechnical engineering modules. This paper presents several approaches adopted by the author in conducting geotechnical module lectures and tutorials at various levels. For junior modules, the author only covers the key concepts from the textbook and facilitates the students to think deeper and independently. 'Poser' questions are provided from time to time to motivate them to delve more deeply into the subject matter. For all levels, actual field case studies are introduced to enable students to appreciate the practical applications of the subject matter.

For graduate modules with a mix of full time and part time students, the students are facilitated to learn from each other. Field problems brought in by the part time students who are practising engineers are shared with the full time students who have no practical experience. The part time students are encouraged to interact with the full time students as many of them graduated sometime back and became rusty in their concepts.

In order not to overload the students, the tutorial classes are divided into active and passive learning teams to facilitate them to learn together without spending too much effort on the large number of topics covered in the modules. The lecture and tutorial styles appear to be able to motivate the students' interests in geotechnical engineering. In addition, they have benefited by learning actively and independently.

In the author's opinion, there is no single winning teaching method. The teaching method developed by a faculty member may not be suitable for another member or another type of module. It is thus important to note that a successful teaching method can be highly open ended and the key is to facilitate learning by the students on the concepts and fundamentals on their own as far as possible.

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