Engineering Geology Education for the 21st Century

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ABSTRACT

A sound background in geology is necessary if geomechanics is to address the changing face of the Earth as shown by recent geohazard events, by continued urban, infrastructure and resource development, and by climate change both in New Zealand and internationally. Engineering geologists provide this background in nearly every engineering consultancy, resource extraction and government institution in Australasia.

We have used recent developments in post-secondary geo-education to create a learning experience that meets the demands of the modern professional engineering geologist. We are developing a revised programme of study that makes use of online and block learning, accommodating a societal need for distance learning. Online interaction with lecturers and fellow students will be used for delivery of subject fundamentals, while application of the concepts to practical examples will be undertaken during short, intensive blocks. This structure will require students to both learn and prepare independently, and increase the amount of experiential learning through project work and involvement with industry.

We present four teaching and assessment techniques that are well suited to delivery through online and block formats, while ensuring that students gain the technical and professional knowledge and skills expected of engineering geologists. Online lecture delivery through interactive podcasts allows students to study the lecture material at a distance, but we stress that this must be coupled with face-to-face time. We use field work, group work and problem solving to allow students to reach the higher levels of learning technical material, such as synthesis and evaluation, while gaining professional skills.

Keywords: tertiary education, learning outcomes, professional development

1 INTRODUCTION

Engineering geology (ENGE) at the University of Canterbury (UC) is delivered as an 8-course plus dissertation programme across three semesters at the postgraduate level. The objective of the programme is professional (rather than academic or foundational) development. Students in the ENGE programme form two broad groups: recent BSc graduates continuing on for a postgraduate degree and industry professionals fulfilling requirements for Continuing Professional Development (CPD) for Professional Engineering Geologists or Professional Engineers. The professionally-focused objectives of the ENGE programme and the need to accommodate working professionals enrolling in a single course influences both the content of the curriculum and the preferred modes of delivery.

The ENGE programme includes a combination of lectures, tutorials, labs and field trips in different proportions for different courses. The structure of the programme is moving toward a block-format in order to better accommodate working professionals. Block-format courses will comprise an intense 1-2 weeks of class time preceded and followed by off-campus reading and assessment and will, by definition, require their own delivery methods. Alternative delivery techniques, such as Inverted Classroom (IC), have been shown to promote technical competencies better than traditional methods (Mason et al. 2013). Thus, we have incorporated different delivery modes within several of the 8 courses using a variety of techniques to deliver lecture material, practical material and assessments. We present a critical review of four of the ways in which our current curriculum helps our students to develop these competencies: self-directed learning, group work, field work and problem solving. The goal of this study is to demonstrate that alternative curriculum delivery modes are effective at allowing students to achieve the technical and professional competencies. For this to be an acceptable form of teaching, however, the learning outcomes and student engagement must be at least equivalent to the traditional format.

2 ENGINEERING GEOLOGY EDUCATION CURRICULUM

The ENGE curriculum at UC comprises 8 courses which are titled: Field Methods, Construction Practice, Rock Mechanics, Soil Mechanics, Hydrogeology, Engineering Geomorphology, Risk Assessment and Projects. These courses were selected under guidance of a technical committee consisting of industry and academic professionals and closely follow the recommendations of the the Joint Technical Committee 3 (JTC3) of the International Society for Rock Mechanics (ISRM), International Association of Engineering Geologists (IAEG) and the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). JTC3 tasks pertaining to engineering geology education are (Vallejo 2010):

- Elaboration and maintenance of a State of the Art Report on Education and training in Engineering Geology (EG), Soil Mechanics (SM) and Rock Mechanics (RM)
- Preparation of Guidelines and Suggestions for University Educational Programs in the Geoengineering disciplines (EG, SM and RM)

JTC3 proposed a competency profile for engineering geology education that addresses both technical and professional competencies (Figure 1), according to Bloom’s Taxonomy (Bloom et al. 1956). The graduate profile for ENGE is in keeping with the recommendations of JTC3, with 4 of the 8 courses (Soil Mechanics, Rock Mechanics, Hydrogeology, Site Investigation) explicitly linked to the technical competencies in Figure 1, in particular addressing Levels 1-4 of Bloom’s Taxonomy. The other 4 courses (Engineering Geomorphology, Construction Practice, Risk Assessment, and Projects) provide linkages across the technical competencies while addressing international (Turner and Rengers, 2010) and New Zealand priorities for geohazards. These courses are aimed at levels 5-6 of Bloom’s taxonomy. The professional competencies are addressed in multiple courses, especially those that include group work or presentations, and are explicitly addressed in the Construction Practice and Projects courses.

In addition to the JTC3 recommendations, we have consulted with a technical committee comprising both industry and academic advisors: they have identified landslides identification, slope stability analyses, geophysics, and engineering geology models as additional core competencies at the postgraduate level. The course in engineering geomorphology explicitly addresses landslide and slope stability analyses (which are also covered in rock and soil mechanics). The concept of engineering geology models that is taught at UC follows recommendations set forth by the IAEG Commission 25, which distinguishes the different types of models and how they may be used (Parry et al., 2014). The concept of engineering geology models addresses Levels 1-6 of Bloom’s taxonomy across multiple core competencies and forms the basis for designing site investigation and appropriate engineering solutions.

3 ALTERNATIVE METHODS OF CURRICULUM DELIVERY

We have incorporated several alternative methods of curriculum delivery, including inverted classroom and an emphasis on presentation and communication. We are critically assessing four of the alternative methods of curriculum delivery, which are: self-directed learning through interactive podcasts, group work, field work, and problem solving. To conduct our research, we examined the learning outcomes through comparison between traditional and alternative teaching using in-class quizzes and mastery assessments; we conducted anonymous interviews (with an objective third party:

ASCE Category	Competency Area	Bloom's Taxonomy Level of Achievement					
		1 Knowledge	2 Comprehens-ion	3 Applicat-ion	4 Analysis	5 Synthesis	6 Evaluation
Foundational	Math						
	Statistics						
	Basic Science						
	Geoscience						
Technical – Engineering Science	Statics						
	Mechanics of Materials						
	Fluid Mechanics						
	Soil Mechanics						
	Rock Mechanics						
Technical – Engineering Design	Numerical Modelling						
	Engineering Geology						
	Hydrogeology						
	Site Investigation						
	Foundations						
	Underground Construction						
Professional	Communication						
	Public Policy						
	Business/ Public Administration						
	Globalisation						
	Leadership						
	Teamwork						
	Attitudes						
	Lifelong Learning						
	Professional Ethics						

Figure 1. Conceptual competency profile for engineering geologists based on the ASCE competency profile, as proposed by JTC3 (modified from ASCE 2008 and Turner 2011); satisfied by: grey – university studies, black – work experience

the Academic Development Group); and we asked the students to complete anonymous surveys. The results reflect the 2013 and 2014 academic years for students in ENGE 412, Rock Mechanics, and ENGE 416, Projects. Class sizes range from 38-52 and 27-29, respectively. The Rock Mechanics course includes 25-30% students in their last year of the BE in Civil Engineering.

3.1 Self-directed learning through interactive podcasts

3.1.1 Method

The interactive podcasts are made up of pre- and post-lecture quizzes, lecture slides and two mid-lecture mastery quizzes. This format is similar to the lecturing format used in the classroom, with the main difference being its delivery via Internet rather than face-to-face. The pre- and post-lecture quizzes are used as a measure of student knowledge gain, while the mid-lecture mastery quizzes are used to reinforce the material being delivered and encourage student engagement. To ensure that the students complete all of the quizzes, as well as work through all of the material, the lecture slides only become available for download upon completion of the mid-lecture quizzes.

The learning outcomes and student engagement are measured using the pre- and post-lecture quizzes, anonymous student surveys, a focussed discussion group coordinated by the academic development team, and analysis of student access data (access time, total time spent on lecture) for the different components of the podcast.

3.1.2 Outcomes

The two main measures of appropriateness for the interactive podcast were the student learning and engagement. In addition, student preference for either delivery mode is important, as that will have implications for both learning and engagement.

The quantitative data, provided by the pre- and post-lecture quizzes show that student learning improved via both delivery modes: 68% in the traditional lecture (n=1) and 43% in the podcast lectures (n=4). More data are required to determine if the difference in learning between the delivery modes is significant, however both show that students learn the material via lectures. The time taken to complete the quizzes decreased 9% between the pre- and post-lecture quizzes during the first podcast and 1% during the second podcast. This supports the hypothesis that students are increasing their learning in that they can complete the quiz in less time, with higher success. The range in decrease requires more data to confidently explain, but is likely related to the clarity and difficulty of the quiz itself, and will thus be variable over a large number of lectures.

Students were required to achieve 100% on the mid-lecture quizzes to ensure that they mastered the material before continuing with the podcast. Student mastery was neither evaluated nor enforced during the traditional lecture, due to the logistics of ensuring a perfect score manually during lecture time. In addition, students worked together on the mid-lecture quizzes during traditional lectures, leading to the potential for students to complete the quiz without actually mastering the material.

On average, 87% of students attended the traditional lectures (n=3), while 88% of students completed the podcast lectures (n=4). This indicates that students are as likely to attend a podcast lecture as a traditional lecture. The first time the podcast was delivered, 76% of students started it between 8-10am and only 4% of students started it after 5pm. The students took better advantage of the flexibility the second time a podcast was offered, with 46% starting it between 8-10am and 11% starting it after 5pm.

Qualitative data from the surveys and focussed discussion group show that the students enjoyed the podcast and found that the flexibility it afforded, especially with respect to pace and the ability to repeat portions, helped them learn the material better. They also appreciated the ability to attend the lecture from home during a wider time frame than a scheduled traditional lecture. Students found that their engagement was higher during the podcasts, and felt that they had to take more responsibility for their learning. Students stated that more material should be delivered via podcast, but they still felt that face-to-face sessions are necessary to address difficult aspects and enhance the mastery of the material beyond what is achieved with the mid-lecture quizzes. The ability to stimulate engagement coupled with mid-lecture quizzes and face-to-face mastery sessions helps the students work towards lifelong learning (a Professional skill), and achieve level 2-3 in Bloom’s taxonomy. Higher levels of learning are attained during set assessments, which incorporate group work, field work and problem solving.

3.2 Group Work

3.2.1 Method

We use group work for a number of applications, including: field work, laboratory work, computational analyses, and large design or research projects. Depending on the desired professional development outcomes, group members can be self-selected or assigned. In certain small-stakes assignments, such as field tasks, small reports or presentations, group members can self-select. In the Rock Mechanics course, with a large number of civil engineering students, groups are assigned such that there is an even distribution of civil engineering students amongst the groups. This facilitates interaction between engineering geology students and civil engineering students, allowing them to combine their different skill sets and approaches to problem solving. This also simulates the work environment into which a large number of these students will eventually go. For the design projects we select the group members according to their project preferences. This allows us to match the student members to their stated interests, and to create balanced groups in terms of aptitude and background.

Students were asked to reflect on the group work and to provide feedback via reflections and anonymous questionnaires. They were asked questions such as:

- How effectively does your group work?
- What behaviours are particularly valuable or detrimental to the team? Explain.
- What have you learned so far about working in a group that you will use to for continuing to work on the project?
- How did you feel about being assigned to work in groups for field and laboratory activities?
- How you feel about balancing Engineers and Geologists in group work?
- Do you think it helps your learning to be working in groups?

3.2.2 Outcomes

One of the key findings of these reflections is the value of communication, which shows that they have reached level 3-4 in this competency. The majority of the groups discussed the need for clear and continuous communication amongst group members. Most of the groups divided the tasks and needed good communication in order to ensure that workflow was maintained, milestones were met and the quality of deliverables was high. Students have made use of a variety of methods for communication and file sharing, including Facebook and Google Docs.

Groups also highlighted the value of good leadership, which shows that they have reached level 2-3 in this competency. While maybe not all team members are effective leaders, understanding the value of a leader is very important for successful group work. We had previously observed that groups with clear leaders tended to be more successful and have thus required students to take on leadership roles their the group work. Groups with good leaders have identified that as a strength, while those with passive leaders have identified that as a weakness. We use fortnightly meetings with the students to provide technical and group management support. In particular, those groups with weak leaders benefit greatly from our moderation during the fortnightly meetings during which they are able to organise themselves and their time for the upcoming fortnight.

We obtained an 89% response rate to the anonymous questionnaire. Some of the questionnaire responses were quantitative and showed that:

- 88% of respondents enjoyed or liked being assigned to groups
- 87% of respondents found that having engineers and geologists in each group was beneficial
- 81% of respondents felt that group work helped their learning

The highly positive response to group work is an indication that the students are practising and achieving success in the teamwork competency at level 3 or higher. Students who elaborated tended to state that group work brought together a variety of skillsets, approaches and work ethics, which increased their ability to master the material. They also appreciated that group work allows them to practise real-world skills that will be helpful in the workforce.

3.3 Field Work

3.3.1 Method

Students do a wide variety of field work as part of the ENGE programme, with the first course offered, Field Methods, focusing primarily on site investigation and engineering geological models. Site investigation has been identified as a core competency at all 6 levels in the JTC3 recommendation, and engineering geological models are the primary method by which we are building skills at Levels 5-6. Focusing on field work, and subsequent data management and geological model building, ensures that students are using consistent, best practice methods for data collection specific to engineering geology. These can be used for engineering-specific analytical techniques such as rock mass classification, numerical modelling and limit equilibrium analyses. In some courses, particularly rock and soil mechanics, the field work is complemented by laboratory testing with reports required to synthesise the field and laboratory components, as would be required in professional practice.

Students were asked to reflect on the group work and to provide feedback via reflections and anonymous questionnaires. They were asked questions such as:

- Did the field assignment help in your understanding of the material?

- What parts in particular were useful, and which parts would you change?

3.3.2 Outcomes

Most students (over 95%) report that the field and laboratory activities enhanced their learning of the material, with two-thirds to three-quarters reporting that it was definitely enhancing (depending on the wording of the question). When asked what parts of the field activities needed improvement, nearly half (46%) did not identify any outstanding issues while 21-34% reported that there were issues needing to be addressed for some very specific activities, with the most common request being more guidance or background for a very specific field activity.

The timing of the field work varied: in some cases, it was the first activity in the course, but in other cases, field work occurred later, after laboratory activities and/or mid-way though the course. There are advantages and disadvantages to each method: bringing students into the field early can aid in understanding difficult concepts later in the classroom (levels 1-2), while having field trips at the midpoint or end of a course allows them to approach the field work with a greater degree of understanding and application (levels 3-4). The disadvantage of having a field activity early in the course is that students sometimes report that they did feel they had enough background to go into the field successfully: in this case, 12% of students felt that some field activities have occurred too early. However, most of the students reporting that field activities were too early were engineering students with little geology background, and many of them also mentioned that having mixed groups (engineering and geology students) mitigated some of the issues around lack-of-background. Thus, we feel that the issue is more lack of geology training for undergraduate engineers rather than a problem with holding field work early in the course

3.4 Problem Solving

3.4.1 Method

Problem solving is not a competency in the JTC3 conceptual profile, however it is a technical section in the ASCE competency profile for civil engineers (ASCE 2008). We argue that problem solving is an overarching competency and propose that, as such, it could fit within the professional classification rather than the technical classification.

We use problem solving as an assessment tool with two desired outcomes: to help students specifically develop problem-solving competencies from a professional standpoint, linked to attitudes and lifelong learning; and to achieve the higher levels in the technical competencies. Students are assigned work that contains open-ended questions where they are responsible for selecting and implementing an appropriate solution. For example, students are tasked with optimising pillar width for two parallel circular tunnels. The technical aspects of the task are not complex, but allow the students to apply (level 4) what they have learned about stresses, strains, strength and yielding. In addition, the students must propose, justify and use criteria for optimising the spacing. This problem solving approach allows the students to synthesise (level 5) their knowledge and evaluate (level 6) their proposed solution to the optimisation question.

Problem solving is also an important component of the Projects course, in which most of the analytical work occurs at the very end of the academic year. Project ideas are generated by industry and academic sponsors, but it is up to the students to write a proposal and decide on the scope, objectives, and methodology (level 3). Completion of the project requires analysis, evaluation, and recommendations, which are skills at levels 5 and 6.

3.4.2 Outcomes

Anecdotally, students find problem solving challenging. The open-ended questions for which there is no specified methodology pushes them out of the comfortable world of students following algorithms, and into the more daunting world of practitioners using their judgement to select the most appropriate solution.

The frustration within relatively short in-course assessment was reflected in the students' reflections and questionnaire responses as a perceived lack of clarity in the assessment brief. As a result, the students often spent time trying to understand the meaning of the assessment brief, rather than solving the problem. We argue that these outcomes are related to the structure of the briefs rather than the assessments themselves. We propose that the portions of problem solving assessments that are formulaic are explicitly highlighted as such, and those that are open-ended are introduced with a discussion of the value and goals of problem solving. The assessments should also be discussed in class, with the inclusion of a model for problem solving so the students can develop the confidence needed to complete the task.

Similar frustrations arise for most of the students during the Projects course, which has the luxury of running over a 16-week period. In this case, the highest period of frustration and difficulty coincides with an impending deliverable, when the students are at the problem-solving phase that requires skills at levels 5 and 6. The Projects course in its present form has been run for 2 years. During the first year, there were three major deliverables, at weeks 2, 8, and the end (16). Of the ten projects, only half (50%) had a clear analysis, conclusion, and recommendation at the end, which indicates difficulty at level 3 and 4. We assessed this outcome partially as a result of a lack of deliverables between weeks 8 and 16, making it easy to procrastinate and avoid the struggle with problem solving.

During the second year, the number of deliverables was increased to five, at weeks 2, 6, 8, 12, and 16. The outcome of that (and other) changes is that all 8 projects (100%) had (or nearly had) a clear analysis and conclusion at the end of week 12, with 4 weeks left to finish. We argue that the additional deliverables have forced the students to face the challenge of problem solving for smaller parts of their project on a more frequent basis, and the improved project results show competency at level 5 or higher.

4 CONCLUSION

We have shown that the learning, engagement and satisfaction of students is the same or better when course material is delivered via alternative rather than via traditional formats. We have also shown that the ENGE programme is in line with the JTC3 recommendations for competency profiles for engineering geology. The course subjects address the technical competencies, while the ways in which the material is delivered and assessed address the professional competencies. The delivery methods we have presented are suitable as an alternative to traditional lectures and to provide the flexibility needed for the new ENGE programme. As the new block-format delivery is developed, the student learning and engagement needs to be regularly assessed to ensure that they remain the same or better compared to traditional lectures.

Programme delivery through block-format using the approaches presented here will provide opportunities to improve graduate recruitment through a focused professional programme that follows IPENZ guidelines and has sufficient flexibility to allow working professionals to enrol. We argue that a balance of alternative techniques and face-to-face lectures, tutorials and workshops is a useful way forward for engineering geology education. Interaction between students and professionals, through class work and project sponsorship, will ensure that graduates are prepared for the 21st Century by being confident communicators, adept at professional judgement and peer review, and follow an ethical approach that recognises the needs of stakeholders.

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