Effective teaching methods for engaging engineering students in geology course

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Abstract: Knowledge of geology is essential for engineering students studying in a postgraduate programme on the management of natural resources and later aspiring to work in a related sector. This paper discusses the diverse teaching methods effectively used for engineering students in a geology course learning about the formation, distribution and preservation of a range of natural resources including hydrocarbons, ore deposits and building stones. The diverse teaching methods include case-based studies, laboratory investigation of hand specimen of rocks and minerals, 3D modelling using an industrial software and field trips that enable students in 3D visualisation of geological structures. Integrating their learnings from the lectures to practical observations and 3D models help in their understanding on the complexity of natural systems. The different teaching methods complement the lectures that are introductory in nature. The assessment methods are also diverse, testing on the identification and description of hand specimen, application of an industrial software for 3D modelling, and recording observations in a field trip to constrain the formation and preservation of economic resources. The end of term assessment is in a multiple-choice questions format to test the application, integration and analysis of taught concepts. The engineering students found group working opportunities with geology students a very positive learning experience. They also indicated preference for multiple assessments as implemented in this module. Their performance in the assessments demonstrate that teaching and assessment approaches implementing diverse methods work well for engineering students, helping them to develop in-depth geological concepts pertaining to natural resources.

Keywords; geology education, engineering students, natural resources, diverse teaching methods, field trip.

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1. INTRODUCTION

1.1 The relevance of geology for engineering students in the natural resource sector

Engineering students can be employed in different fields of natural resources including the energy, mineral and water sectors. In the current age, engineering needs a more holistic approach with emphasis on sustainable exploitation of natural resources, with minimal impacts on the environmental natural systems. It is important that engineers integrate geology and engineering knowledge to focus on the current issues of resource development and climate change. Geology undergraduates, have a strong understanding of different Earth materials including their identification, origin and processes of formation followed by their distribution on Earth to enable them to make critical contributions to develop sustainable environmental practices. They undertake fieldwork training with opportunities to visit active areas of industry such as quarrying and large-scale mining or on-shore oil and gas fields to enhance their understanding on complex natural systems. Engineering graduates have transferable skills such as strong IT and technical skills along with numeracy proficiency, with ability to focus on details. In addition, they also have strong problem solving skills with ability to work as team. All these skills are essential in a geology course and can be used to the best advantage, especially since the future will need multidisciplinary perspectives encompassing both engineering and geology for Earth resources exploitation and sustainable development (Iwuji et al., 2015).

One of the challenges when it comes to the engineering students in a postgraduate geology course is their lack of exposure to geology previously, as it is rarely taught as a standalone subject in the school curriculum with limited content integrated into different subjects such as geography, physics and chemistry. In addition, their exposure to sustainability and environmental issues tend to be limited. Another challenge engineering students face is, visualisation of geological structures in 3D from topographic maps and limited exposures, which is very important to constrain reserve estimates of the different resources, as well as take decisions on their extraction with minimal environmental damage. Besides, engineering students lack experience in the holistic understanding of the complexity of different natural systems. For example, a sedimentary basin can extend hundreds of kilometres laterally with depths of up 100s or 1000s of metres. They host different key natural resources in pockets or dispersed over a wide area, including non-renewable (conventional and unconventional hydrocarbon deposits) and renewable (e.g. geothermal), groundwater and ore minerals with occurrences controlled by an interplay of different geological events including tectonic, climatic, biologic and oceanographic in the life of the basin. In order to constrain the temporal evolution of the basin and the distribution of these critical resources, it is important to elucidate the complex interplay of paleo-stress, paleo-temperature, and paleo-rheological properties of the sediments in the context of basin forming mechanisms.

In spite of its significance, there are a very few studies that focused on the pedagogical approaches appropriate for a geology course delivered to engineering students. In this study we use students' scores and feedback from surveys for four years (2016-2019) before the pandemic, to assess the effectiveness of implementing different teaching approaches along with diverse assessment methods for a geology module taught to engineering students. While the methods of teaching and assessment may deviate from traditional geology courses, they should be fit for purpose with relevance to the intended learning outcomes without compromising with academic standards. They should take into account available resources within the scope of the module, including students' and staff time.

1.2 The taught module: Geology for Global Managers and Engineers

The module Geology for Global Managers and Engineers (GGME) is taught to students in the first semester, undertaking the M.Sc. Global Management of Natural Resources (GMNR) Program in the Chemical Engineering department of University College London. This mandatory module is worth 15 credit points of the 180 credits for the programme. The number of students in the GGME module were 11(2016-17), 19(2017-18), 31(2018-19) and 41(2019-20), of which, the engineering students comprised of 36% (2016-2017), 32% (2017-2018), 16% (2018-2019) and 7% (2019-

2010) of the total. Of the rest of the students, some had geology background, with others came from different academic disciplines (e.g. environmental science, management). Aligned to UCL guidelines, this 15-credit module for postgraduate taught students make up ~ 150 hours of study that include lectures and laboratory work along with a short, local day field trip and an industrial software training, alongside assessments and self-study time. In addition, a mid-term five-day field trip to the south coast follows the first five weeks of study during the reading week.

In this module, the students learn about the formation and distribution of rocks on Earth and the associated mineral and energy resources, to understand the implications of their spatial and temporal distribution on their extraction from economic and environmental perspectives. On successful completion of this module, students should be able to identify common rocks and minerals with an understanding of their occurrences and distribution on Earth. They should be able to visualize geological structures in 3D to place quantified constraints on the natural resources they host.

2. TEACHING AND ASSESSMENT

Methods	Description	Hours	Bloom's taxonomy*					
			K	C	Ap	An	S	E
Lectures	(Introductory): Characteristics and classification of common rocks and minerals; Identification of geological structures; geological processes responsible for the formation of hydrocarbons and ore deposits.	10						
	(Invited – industrial speakers): 1. Aspects of economic exploitation of minerals from their natural deposits, to distribution in the market. 2. In situ, subsurface record of geologic formations based on well logging as used in the hydrocarbon industry.	2						
Case studies	Weathering of diverse building stones in different heritage sites (e.g. Tower of London, Angkor Wat in Cambodia) to relate the complex interaction of the stone with its natural environment.	4						
Practical activities	Laboratory investigation of the properties of common rocks and minerals of economic importance and geological structures of hand specimen on display.	10						
	(Field trip 1): Study of building stones in the British Library to constrain their deterioration with time. (Field trip 2): Record the geology and geological features of field trip locations (in Dorset); Constrain the entrapment of hydrocarbons in the context of basin evolution (Wessex Basin).	20						

Software modelling	3D geological reconstruction of the Wessex basin relating to field trip observations.	6							

*K: Knowledge; C: Comprehension; Ap: Application; An: Analysis; S: Synthesis; E: Evaluation

Table 1 The teaching methods employed in this module with relevance to Bloom's taxonomy.

2.1 Teaching strategies

Problem finding and problem solving are two, strong engineering traits referred to as engineering habits of mind (EHoM) that are incorporated in engineering education (Royal Academy of Engineering, 2014). Engineering students learn the best when they can apply taught basic concepts to solve problems, which, is central to all the teaching elements of this module. Following this strategy and employing diverse teaching methods, this exceeds the college recommended 40 hours of face-to-face teaching. However, some of the teaching sessions in the field and laboratory also incorporates assessment activities. The teaching methods follow Bloom's Taxonomy (Armstrong, 2010), providing a pathway for the learning process by progressively increasing the students level of thinking (Table 1).

2.2 Pre-course materials

While designing the teaching materials for GGME, it is important to take into account that the students in this module have diverse academic background with schooling in different countries. Consequently, they possess different levels of prior geology knowledge. A set of pre-course materials designed for students with no prior geology learning, covered some elementary topics taught in some of the secondary schools of UK and US as a part of their geology curriculum. They include rocks, minerals and fossils, Earth structure, plate tectonics, volcanoes and earthquakes and geologic time. The students can access these resources before the commencement of the term teaching. Although it is challenging to engage students with these materials beyond the classroom at this very early stage, few students did give the feedback that these materials heightened their preparedness for the module, enabling them to participate in class discussions from the beginning.

2.3 Lectures

Instead of traditional in-depth lectures, the lectures are introductory to familiarize students with the basic geology concepts relevant to the formation and distribution of natural resources without emphasis on increasing students' depth of knowledge (Table 1). The lecture sessions are interactive, where students feel encouraged to ask questions.

Lectures by industrial speakers is an integral part of this module. Besides networking opportunities, they provide real examples from the industry to help students structure their knowledge and inform them how their learning is relevant to the industry (Royal Academy of Engineering, 2016). As examples, an economic geologist from Roskill, which is a company with expertise in global metals, minerals and end-use markets, presented on 'Nickel and chromium: from the mine to the market.' The talk focused on deposits and concentration of these critical metals, predicted extraction, as well as demand and supply over the next few decades, strengthening students' understanding on the geological processes responsible for the formation of these ore deposits and their distribution, with impacts on their extraction and supply to meet global demands. The second lecture on the application of well logging in the hydrocarbon industry, improves students' understanding on the subsurface reservoir properties with subsequent application to 1D basin modelling using the industrial software (Permedia). Although it is challenging to coordinate the invited talks within the module timetable, it helps to plan the presentations with the speakers well in advance, which also ensures that the presentation contents provide a context for the module.

2.4 Practical sessions

The practical sessions complementing the lectures, fieldtrips and software modelling emphasizes on the applications of learnt concepts to integrate observations and interpretation into a comprehensive sense of conceptual understanding (Table 1). For example, while students study about the mineralogy of rocks and their texture, they follow it up by observing hand specimen of samples in practical classes. They further correlate the observations to the preservation of different rock types in built structures through case studies, analysing their suitability of use in the structure and recommending better alternatives in a following field trip.

Through collaboration with the industry, students gain access to an industrial software (Permedia) for basin modelling that particularly helps engineering students to link multiple, complex geologic processes in a model space-time frame. The industrial engagement of this module was a positive contributing factor during the accreditation of the GMNR programme by the Institute of Materials, Minerals and Mining in 2021.

The two mandatory field trips for this module enable students to consolidate their knowledge by relating theoretical information to field observations. The field manual guides are available to the students in advance of the trip. A high, staff to student ratio (1:8) helps to provide enhanced support to the students while in the field. The fieldtrips complement the introductory lectures and practical sessions, to emphasise how careful observations can lead to predictive insights on basin evolution and formation of associated natural resources. Later, students get an opportunity to place the observations in spatial and temporal contexts by 3D modelling using the Permedia software. Students work collaboratively in preset groups with scope for peer feedback. Each group is gender balanced and include students from different academic backgrounds. Peripherally, students get leadership opportunities and build their awareness of health and safety and outdoor risk assessment during off-site working. There is a marked increase of motivation and interest in learning during the two field trips. This is evident from the following testimony by one engineering student from the GMNR programme: 'Whilst I have many fond memories from my time on the programme, I consider our field-trip to Dorset in November of 2017 as a personal favourite. Not least because of the amazing scenery, but also because it really did help bring to life a number of geological concepts we had been learning about in the weeks leading up to it.' The major constraints in running field trips is the pressure on resources related to organising and running them efficiently, including staff and students' time and expertise of staff running them. Since the Earth Sciences department in UCL administers this module where there is a strong emphasis on field training, there is a structured departmental guidance and support to field trip leaders to run these trips.

2.5 Case studies

Case-based method for teaching geology can be very effective to promote student engagement and enquiry (Goldsmith, 2011). In this module, students learn about the broad divisions of hydrocarbon reservoirs based on trap formation, the structural, stratigraphic, lithological and the combination traps, using classical case studies of the Rotliegend gas play from the southern North Sea and the

Abadan Plain Basin from the Middle East around the Persian Gulf (e.g. Corona, 2005; Atashbhari et al., 2018). Based on these cases, the students critically analyse the capability of a basin to accumulate hydrocarbons and apply these in-depth concepts in the fieldtrip when they visit Dorset to study the evolution of the Wessex basin.

2.6 Assessment methods

The assessments not only address the learning outcomes of the module, but the variety of assessment styles ensure that no student is able to outshine others without having to stretch themselves (Table 2). In addition, each student is likely to find at least one style of assessment more comfortable that can reduce his or her stress level. The group assessments open up learning opportunities for students encouraging discussion and peer feedback within each group. The assessments progressively become more challenging, analysing deeper understanding of concepts (Figure 1). The multiple assessment points, along with formative assessments, help to provide timely, forward-looking feedback to the students, relevant for later assessments.

Method of assessment and description (weightage in %)	Assessed learning outcomes	Assessment week(s)	Selected Students' comments from survey
Laboratory practical work (10) Identification of common rocks and minerals and geological structures (in class group work).	Classification, identification and mineralogy of common rocks.	3, 7	Difficult and tests recall of information. Learning experience enhanced by working in a group.
Report (6) Assessment of the mode of decay of building stones in British Library.	Identification of common building stones and knowledge of their potential preservation over time.	5	The early feedback was helpful. Difficult as too early and no prior subject background.
Field trip activity (12) Recording geological observations and logging sedimentary sequences (in field group work). Individual work: Assessment of the hydrocarbon potential of the Wessex basin based on field trip observations.	Identification of rocks in the field and relating them to potential subsurface energy deposits.	6, reading week	Challenging but a very good learning experience working in a team.
Software modelling (12) 3D modelling	Interpretation of 3D deposits.	9	A very well prepared manual with clear instructions. More practice with activities will be good.
Multiple choice questions (60) Assessment of concepts and their applications, with a mix of questions addressing basic recall to requiring multi logical thinking (final examination).	Knowledge on the formation and distribution of rocks and mineral and their implications for their exploitation from the environmental perspectives.	10	Covered all topics with very good distribution of marks. It was challenging.

Table 2. Diverse assessment methods for GGME and their relevance to the learning outcomes.

3. EFFECTIVENESS OF DIVERSE TEACHING AND ASSESSMENT METHODS

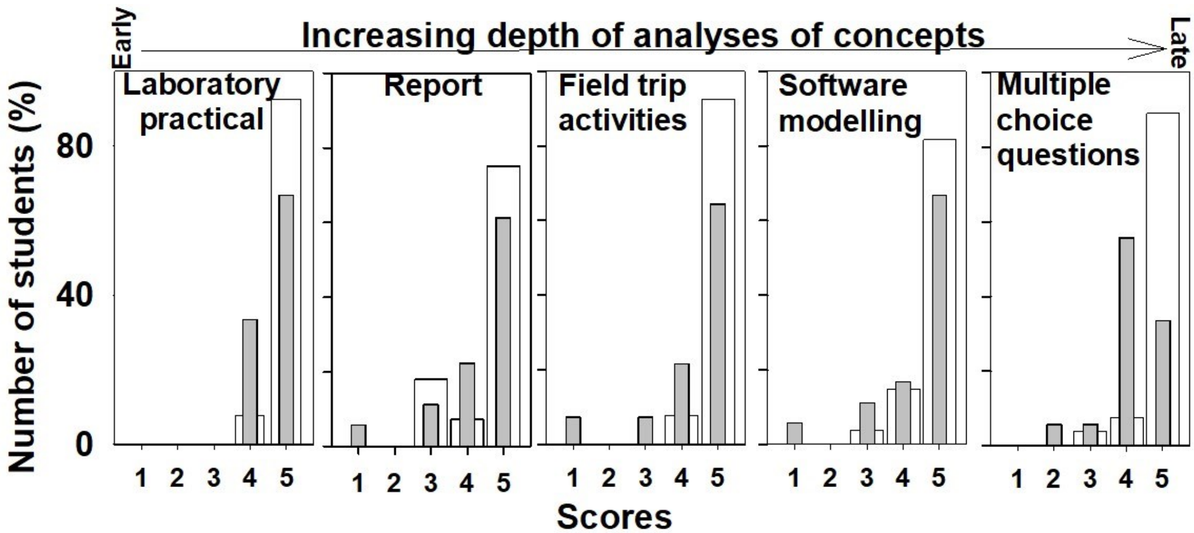

Figure 1 Scores of engineering (grey bars) and geology (white bars) students in different assessments across the term for the GGME module. Scores represented as 1 (0-34%), 2 (35-49%), 3 (50-59%), 4 (60-69%) and 5 (70% and above).

Effective teaching is difficult to assess and requires consideration of multiple facets (Simonson et al., 2022). Students' attainment in a course is one of the parameters for preliminary evaluation of teaching methods. For this module, analyses of the suitability of the diverse teaching and assessment approaches for the engineering students was based on the comparison of the summative assessment scores between engineering and geology students. The geology students outperform the engineering students in the overall module and in the different assessments. The scores of the engineering students are distributed, with many of them exceling in the various assessment components (Figure 1). As the assessments progressively delve into deeper understanding of concepts, survey results show that both engineering and geology students perceive this as increasing challenge in the assessments. The geology students find the first two assessments to be easy while the engineering students find them moderately challenging but both groups of students find the later assessments to be moderately to highly challenging. There is a consistency in the overall performances of both the groups of students suggesting that the different assessment points help them all to progressively develop their understanding of complex geological concepts. Except for some adjustments discussed earlier, teaching geology to engineering students does not need to be markedly different from teaching geology students. Multiple assessment strategy put pressure on both students' and staff time. But surveyed engineering students preferred multiple assessments with the prospect of working in groups with geology students and, opportunities to receive early and continuous feedback (Table 2).

4. FUTURE PLANS

The online teaching resources developed for this module during the pandemic, can replace some of the face-to-face lectures with some of the lecture hours to be used for discussion sessions. The virtual field trip can be for the preview and post review of the trip. The module will incorporate appraisal of carbon capture and storage potential of subsurface basins and assessment of geological hazards in Dorset, to make the teaching content relevant to global challenges. It will be important to see how engineering students can he incentivised for engaging in pre-course material.

5. CONCLUSIONS

In order to teach geology to engineering students with no prior exposure to the subject, diverse teaching and assessment methods have been successfully applied for a 15-credit geology module in a M.Sc. programme on the management of natural resources. The study shows that it is best to limit lectures to no more than 20% of the total teaching time, covering only the basic concepts. For more in-depth teaching, there should be focus on the engineering traits of problem solving and practical skills. This can be achieved by embedding case studies and practical study of rocks in hand specimen and *in situ* in the field. Students can be trained in the application of a 3D modelling software to relate their field observations to geological models, to understand the development of resources in time-space. Multiple assessments points, with both individual and group work can be effective for providing feedback, besides monitoring students' progress in mastering complex concepts.

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