Engineering the Civil Engineering Education: A Capstone Case Study in a Malaysian University

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Abstract—**A Capstone course was introduced to a batch of graduating students in January 2011, aimed to strengthen the co-curriculum of a Civil Engineering degree programme. Comparison is made on the performance of three different batches of students. This paper highlights the improvement in grade distributions outcomes of a comprehensive engineering test introduced to the second and third batches. It is widely indicated that such all-inclusive assessment could positively impact the graduating students professionally. This is indeed an exciting development in engineering education as Capstone is not a familiar feature for Malaysian universities.**

Keywords—engineering education, Malaysian university, Capstone, Civil Engineering, Outcome-Based Education (OBE).

I. INTRODUCTION

Pursuant to the Board of Engineers Malaysia (BEM) acceptance as the 13th signatory of the Washington Accord in June 2009, the Engineering Accreditation Council (EAC) becomes instrumental in ensuring Malaysia's accredited engineering programmes are substantially equivalent to the stipulated standards [1]. Signatories are committed to the development and recognition of good practices in engineering education for the graduate engineers intending to practice at the professional level [2]. Through the initiatives of the EAC, all bachelor degrees in engineering are required to implement Outcome Based Education (OBE). This move is in line with a global paradigm shift in the education sector towards OBE, in meeting the demands of the industries and globalization [3]

OBE implementation emphasizes progressive pedagogical methods such as team-based learning activities, connecting content to real-life situations and integrating content across disciplinary boundaries. This reform aligns with the mission of Universiti Teknologi PETRONAS (UTP) Malaysia which is to produce well-rounded graduates [4]. In complementing their technical competencies, UTP aspires for its graduates to be *well-rounded*, characterised by possessing lifetime learning capacity, critical thinking skills, communication and behavioural skills, business acumen, practical aptitude and solution synthesis abilities. With all of the aforementioned criteria in mind, the Civil Engineering Department of UTP has developed and implemented a Capstone design course for its graduating students in 2011. It sets out to introduce students to professional engineering practice, to demonstrate the consummation of engineering knowledge and soft skills, to allow students to harness technical knowledge and capabilities and to provide an appreciation of the societal context of engineering.

Capstone design courses are a common component of engineering curricula all over the world. They offer students an integrated platform to perform 'professionally' and to demonstrate the culmination of engineering knowledge and soft skills. As such, it is the perfect mechanism for the delivery of an OBE. This course is also in line with what is emphasized by the American Society of Engineering Education (ASEE) that engineering education must provide technical knowledge and capabilities, flexibility, and an understanding of the societal context of engineering [5]. An underlying challenge in evaluating the learning objective of a Capstone design course is that it is impossible to adopt 'one-size-fits all' assessment model. Each assessment strategy must be tailored to fit the needs and education mission of the university.

This paper discusses the development, implementation, objectives and assessment of this Capstone design course, known as Civil Engineering Design (CED). The results of this study are the first step in understanding, assessing and ultimately improving the engineering Capstone education, which indirectly impacts the university's industry reputation and ranking.

II. CAPSTONE EXPERIENCE

The Boyer Commission [6] defines the Capstone experience as follows: "All the skills of research developed in earlier work should be marshaled in a project that demands the framing of a significant question or set of questions, the research or creative exploration to find answers, and the communication skills to convey the results to audiences both expert and uninitiated in the subject matter". Capstone courses typically bring together knowledge from the respective discipline into a culminating learning experience for deeper understanding of the discipline. These courses, by definition, must lead to a summative product such as a project, a paper, a proposal, or a performance. There are many variants of engineering Capstone courses. They range from design projects for final year students implemented within the confines of the university to industrial initiatives which involve dealing with real-world professionals. Capstone projects could even be a revenue generating opportunity for the university. While Capstone courses are typically expected to take place during the final year of the undergraduate curriculum, they can be implemented within a range of one semester to a whole academic year.

In essence, Capstone projects have been termed to be a form of 'authentic assessment' as students are challenged to connect previous coursework and/or internship experiences in a real-world scenario which an engineer may be expected to face upon graduation. Dealing with issues of liability, sustainability and project management, for instance, will equip students with skills and knowledge of a competent engineer. The benefits of Capstone projects are unique and well documented in the experience of the University of California Berkeley. The UC Berkeley found that Capstone experiences are valuable not simply for the opportunity they afford the student to demonstrate mastery of skills and knowledge in a specific discipline but also represent the culminating expression of a broad education and the outcomes that prepare students for future success in a wide range of personal, professional, and civic endeavors [7]. In UTP, Capstone differs fundamentally from other courses offered in the program, principally in the following ways:

- Open ended design problem: There is no single 'correct' solution to an open-ended design project. Students are expected to identify, to evaluate and to justify a recommended design from an array of possible solutions. Throughout the course, trade-offs in dealing with real-life technical and non-technical constraints must be managed and implemented.
- Independent learning: Fundamentally as a project based course, students are required to be independent learners and to be engaged in the analysis, synthesis and application of past curriculum. Capstone design courses provide means to establish links between areas of knowledge within the program and to holistically evaluate students' hard skills and soft skills by graduation.
- Transition into workforce: Students are encouraged to look forward to their transition into working life by building on experience from the project-based course. It was through this exercise that tertiary institutions realize that there is a gap between academic study and the industry. Hence, this university is addressing this gap through the Capstone course. In fact, in the United States of America, the Accreditation Board for Engineering and Technology (ABET) mandated that a four-year Engineering or Engineering Technology curriculum must be furnished with a Capstone course.

III. CAPSTONE COURSE DESCRIPTION

Within the curriculum of B. Eng. (Hons) Civil Engineering, Capstone is offered to graduating Civil Engineering undergraduates in two parts, namely Capstone I (2 credit hours) and Capstone II (3 credit hours). Students form a 5-member team which functions as a real-life project team in an "engineering consulting firm". On top of that, each team is required to elect its own project manager. Capstone I addresses key issues related to the initial planning stage and development of a chosen project, the conceptual planning and design stage of an engineering project. Students will integrate all acquired academic knowledge from previous course works into a real-life design and implementation regime for Capstone II. Students are exposed to standard contracting terms, procurement standard and requirements, interpretation of concept design into actual design, preparation of traffic and environmental impact assessment and other necessary project documents.

Students are equipped only with basic client brief and architectural drawings to proceed with their project. They are expected to assess and justify their proposed design based on sound technical considerations, financial feasibility, and sustainability of the design as well as best project management strategy.

To complement the project, lectures on specific topics related to the development of the project are held on a weekly basis. The lecture series are mainly delivered by a professional engineer with more than 25 years of consulting experience, assisted on the fundamental engineering topics by other academics in the Civil Engineering Department. Students are exposed to both technical and non-technical know-hows of the industry; from client relation management, statutory requirements and submission to local authorities to the other end of the spectrum with offshore structures design and geotechnical considerations. Adjunct lecturers are identified from the industry, which would contribute to at least 15% of the given lectures.

The main deliverables for the Capstone course includes a detailed project proposal outlining the required scope of work. At the end of each semester, students are required to communicate the results of their projects via a formal presentation to their 'clients', which are made up of a panel of faculty members. As outlined in Table 1, each team is to select one project from a list of industrial-linked projects on onshore and offshore development. Projects offered cover an array of designs; ranging from fixed offshore structures to onshore mixed development and industrial developments.

The output of the project is subjected to group-based evaluation. Meanwhile, 20-30% of the total assessment is individual based, i.e. tests. The scope of projects and details for each batch are as illustrated in Table 1. To improve grade distribution and gauge the level of fundamental knowledge for Civil Engineering graduates, a comprehensive test was introduced to the Batches B and C. The reason for the implementation of the comprehensive test will be discussed in the following section.

TABLE I. ASSESSMENT STRUCTURE AND SCOPE OF PROJECTS

Semester Enrolled	**Batch A Jan-May 2011**	**Batch B Sept 2011–Jan 2012**	**Batch C May–Sept 2012**
Group Assessment (Project - 70-80%) Scope	Oral presentation – 80% Report – NA Design project: • Offshore oil platform – (topside & jacket) • Onshore: a. 8-storey Specialist Hospital b. 8-storey Mixed Development c. 60-tonne capacity Oil Palm Mill on 10-acre lot d. 13-storey office building	Oral presentation – 50% Report – 20% Design project: • Offshore oil platform – (topside & jacket)\ • Onshore: a. 7-storey educational building & other units b. 18-storey condominium & mixed development	Oral presentation – 50% Report – 20% Design project: • Offshore oil platform – a. 4-legged jacket & topside b. Monopod & topside • Onshore: a. 18-storey condominium & mixed development
Individual Assessment (Test - 20-30%)	Take Home – 20%	Take Home – 15% Comprehensive 8-hour– 15%	Take Home – 15% Comprehensive 8-hour– 15%

The Institution of Engineers Malaysia (IEM) has identified five important criteria for the Malaysian Engineering Education Model [8], namely scientific strength, professional competencies, multi-skilled, well respected and potential industry leader, and finally morally and ethically sound. Based on the description of the course, it shows that both CED I and CED II fulfil at least four out of the five important criteria in the model.

A. Comprehensive Test

Through benchmarking visits to two local universities, it was found that such comprehensive assessment could positively impact the employability of graduating students. Furthermore, it was found after Batch A was completed, the grade distribution was highly skewered to the left i.e. 21% students obtained grade A. This indicated the need for the assessment components to be more representative of their level of understanding and culmination of engineering knowledge. Therefore, a comprehensive test was introduced in the second batch onwards, Batch B and C. The comprehensive test was developed to mimic the practice of the 8-hour written Fundamentals of Engineering (FE) examination in the United States for engineering graduates to be recognized as an Engineer in Training (EIT) [9], which is the equivalent of a graduate member of the BEM. This open-book comprehensive test covers six fundamental questions related to key areas of civil engineering, to be completed within eight hours. It addresses the culmination of engineering knowledge for Capstone students, which were not adequately addressed in Batch A. The changes in assessment components distribution (Table 2) has also influenced the overall grades, as discussed in the next section.

In the perspective of OBE, this test correlates to 10 of 11 program outcomes (PO) set for B.Eng (Hons) Civil Engineering, as accredited by the EAC. The comprehensive test is a measure of these attributes prior to their graduation and upon graduation, the Civil Engineering programme educational objective (PEO) will then take over. On top of that, students are actively encouraged to register with BEM upon graduation from the programme, thus improving the curriculum on Capstone substantially.

IV. OBSERVATIONS AND ANALYSIS

This study analyses and compares the performance between the three batches of students that had taken the Capstone project which are: Batch A in January 2011 semester, Batch B in September 2011 semester and Batch C in May 2012 semester. Table 2 illustrates the detailed percentage breakdown of assessment structure for the course based on the semester. As stated in the abstract, the focus of this discussion is on the implementation of comprehensive test, which is an improvement on assessment components mainly to address culmination of engineering knowledge as per WA and EAC requirements.

TABLE 2. PERCENTAGE BREAKDOWN OF ASSESSMENT STRUCTURES FOR CAPSTONE I AND CAPSTONE II.

Semester Enrolled	**Batch A Jan-May 2011**	**Batch B Sept 2011–Jan 2012**	**Batch C May–Sept 2012**
	Percentage breakdown		
Assessment Structure Capstone 1	Project presentation – 80% Report – NA Test – 20%	Project presentation – 80% Report – NA Test – 20%	Project Presentation – 60% Report – 20% Test – 20%
Assessment Structure Capstone 2	Presentation – 80% Report – 10% **Test – 10%**	Presentation – 50% Report – 20% **Test 1: Take Home – 15%** **Test 2: Comprehensive 8-hr test – 15%**	Presentation – 50% Report – 20% **Test 1 – 15%** **Test 2: Comprehensive 8-hr test – 15%**

Figure 1 below compares the overall grades obtained for Batch A, Batch B and Batch C. Only results of CED II are used as a yardstick, given the extensiveness of the full professional presentation and 8-hour comprehensive test.

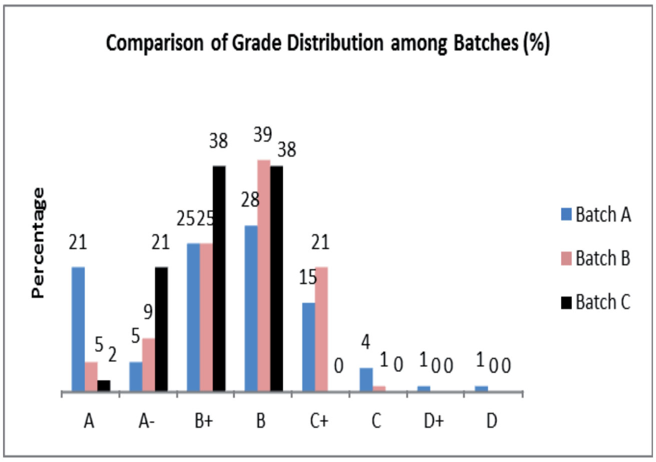

Figure 1. Overall grade comparison for Batch A, Batch B and Batch C

The results comparison shows 21% of students in Batch A made A grade, which is a considerably high, with a large gap to the A- grade. Whereas the distribution is more uniform and normal for Batch B and C. The improvement in overall grade distribution is observed to be related to the increased percentage of individual assessment components, from 10% to 30%, and the introduction of comprehensive test in the assessment (15%). Upon closer observation, comparing the results of Batch B and C, there appears to be an improvement in the overall grade of Batch C, whereas a more uniform distribution for Batch B. The results of Batch B and C, both subjected to a comprehensive test, appear to obtain an improvement in the overall grade for the latter.

The findings indicate that the comprehensive test introduced to Batch B and C is a truer measure of a student's performance. As it is an open-book test, it reflects a student's understanding and synthesis of past fundamental courses collectively in a written test format, rather than the lower cognitive of memory dumping in conventional closed-book test set up. The reported comprehensive test grades comparison for Batch B and Batch C is shown in Figure 2.

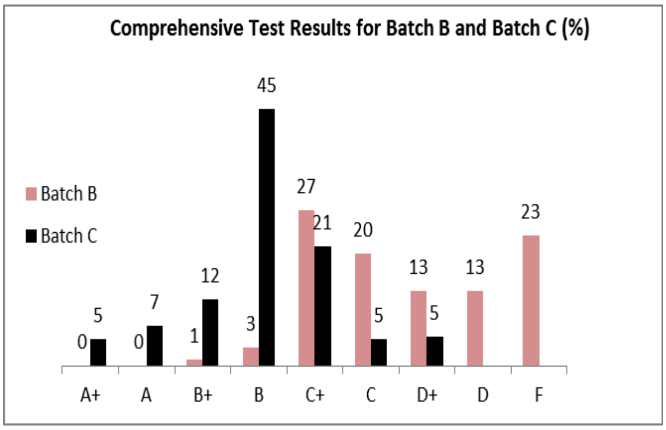

Figure 2. Grade comparison for comprehensive test results for Batch B and Batch C

The results of the comprehensive exam indicate that Batch C students showed an improved and normally distributed performance, as compared to the right-skewed performance of Batch B i.e. students did not perform very well at the test. This may be contributed by efforts of Continual Quality Improvement (CQI) done at the end of every batch. This ensures continuous changes are implemented in courses and the curriculum in order to achieve the stipulated programmed outcome.

The results from comprehensive test in Batch B were analyzed to determine why students did not do well despite it being an open-book assessment. It was found that students scored badly for question 4 and 5 related to wastewater and hydraulics. Critical analysis of the answers given found that, "none of the students were able to answer the sub-question (iii) regarding the biomass produced and (iv) regarding the volume of aeration tank correctly. Most were not sure which formula to use in those sub-questions" and "none of the students answered correctly as indicated in the answer scheme". These findings lead us to revise the test to be more flexible, whereby in Batch C the comprehensive test offers 7 questions in fundamental engineering areas and 1 engineering economics. Students can choose 7 of 8 questions. This was found to significantly improve the students' performance, as depicted in Figure 2.

V. WAY FORWARD

As Capstone is relatively a new course in UTP, analysis done on the performance assessment of the past batches is at best, a hypothesis for the department to work on. To accurately determine the outcomes and key performance factors of this Capstone design course, more assessment tools and policies can be implemented. Aside from the CQI, information on the achievement of the course outcomes will be derived from further research on the following:

- To find out to what extent the complex problem solving in Capstone creates better understanding for Civil Engineering students
- How do students experience working in a group and to what extent does it improve their soft skills through oral presentation.
- Incorporate feedback from existing students, alumni and faculty members (to increase reliability of hypothesis formed here)
- Implement benchmarking exercises with other similar courses

VI. CONCLUSION

The stated objectives of Capstone are to introduce students to professional engineering practice, to demonstrate the culmination of engineering knowledge and soft skills, to allow students to harness technical knowledge and capabilities in solving complex problems and to provide an appreciation of the societal context of engineering. This paper only focuses on the comprehensive test, one part of the assessment components in

Casptone. The findings suggest that the introduction of comprehensive assessment have partly fulfilled the objective related to culmination of engineering knowledge. Future researches will be carried out to address the areas outlined in the previous section V on way forward.

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