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# INFUSING INDUSTRY PRACTICES INTO AN ENGINEERING CAPTSONE PROJECT: A LEARNING OUTCOME ATTAINMENT CASE STUDY

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**Abstract**

A capstone project in current engineering education is often introduced to enable the holistic attainment of engineering knowledge by an engineering undergraduate. Essentially project-based in nature, there exists a need to ensure that part of the attainment process involves key industry practices – such practices being necessary in attaining the status of a professional engineer. Herein lies the synergy that can be made use of between industry and academia. By exposing engineering undergraduates to a project which addresses an engineering challenge and providing them with the opportunity to learn from professional engineers who are experts in the fields of safety, sustainability, quality management, ethics and project management, this culminates in the implementation of a prototype design which incorporates the amalgamation of knowledge from industry and academia. This paper presents the unique curriculum developed in a capstone project module, incorporating learning sessions from professional engineers in the five (5) key areas of industry practice highlighted above and how these have contributed to significantly enhancing the learning outcome and hence programme outcome attainment of the engineering undergraduates who have experienced the module.

Keywords: Capstone projects, Industrial practice, Outcome-based-education.

## 1. Introduction

The current state of engineering education is swiftly progressing in the direction of inculcating practical experience in a theoretically based environment. The need

**Abbreviations**

| | |
|---|---|
| ASME | American Society of Mechanical Engineers |
| BEM | Board of Engineers Malaysia |
| CDIO | Conceive, Design, Implement, and Operate |
| CQI | Continual Quality Improvement |
| EAC | Engineering Accreditation Council |
| EAC | Engineering Accreditation Council |
| EPAM | Engineering Programme Accreditation Manual |
| ESAT | End of Semester Assessment Tool |
| EVM | Earned Value Management |
| KPI | Key Performance Indicator |
| LO | Learning Outcomes |
| ME | Mechanical Engineering |
| MEGP1 | Mechanical Engineering Group Project 1 |
| MEGP2 | Mechanical Engineering Group Project 2 |
| OBE | Outcome Based Education |
| PDCA | Plan-Do-Check-Act |
| PO | Programme Outcomes |

for this has been created by the stakeholders (namely industry based engineering experts) of engineering programmes across the globe, who have articulated a need for more well-prepared graduates. The most obvious way of ensuring that graduates are well prepared is to have a curriculum which substantially covers all aspects of relevant areas of engineering – which of course means significantly overloading the students and going much higher than the minimum credit bearing as indicated by the relevant engineering accreditation bodies. In addressing this challenge, we found that the most efficient way to handle this was through the implementation of a capstone project module, which is able to amalgamate industry based experience with theory, and is project based. Hotaling et al. [1] indicated that in order for engineering students to excel and advance in industry, it is the role of the university to ensure that courses reflect as many industry based challenges as it is realistically able to do. The authors also state that the objective of a capstone project course is to infuse practical experience into current academic curriculum and employ a project-based learning pedagogical approach.

All degrees offered by Malaysian based Universities are encouraged to seek accreditation by the Malaysian Engineering Accreditation Council (EAC) which is part of the Board of Engineers Malaysia (BEM) – a statutory body whose primary role is to facilitate the registration of engineers and regulate the professional conduct and practice of registered engineers in order to safeguard the safety and interest of the public. A graduate with an accredited degree would be recognised by institutions and countries that are part of the Washington Accord (Malaysia being a signatory) and more importantly are able to register with BEM – a legal requirement in Malaysia. The presence of an accrediting body drives the initial design in relation to the academic curriculum. Generally speaking, engineering programmes in today's day and age would need to cover a variety of modules that are aimed at producing competent graduate engineers who excel in both the technical and social areas. Bordogna et al. [2] insisted that the main focus of engineering education should be to develop the students' capabilities in integrating, analysing, innovating, synthesizing and understanding challenges in a contextual manner – this is in essence what a student should be capable of achieving upon graduation.

The Malaysian Engineering Programme Accreditation Manual (EPAM 2007) [3] published by EAC indicated eleven (11) key outcomes an engineering student is expected to attain upon graduation – thus defined as the Programme Outcomes (POs). The POs are as follows.

1. Engineering Knowledge - Apply knowledge of mathematics, science, engineering fundamentals and an engineering specialisation to the solution of complex engineering problems;
2. Problem Analysis - Identify, formulate, research literature and analyse complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences;
3. Design/Development of Solutions - Design solutions for complex engineering problems and design systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations;
4. Investigation - Conduct investigation into complex problems using research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of information to provide valid conclusions;
5. Modern Tool Usage - Create, select and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modelling, to complex engineering activities, with an understanding of the limitations;
6. The Engineer and Society - Apply reasoning informed by contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice;
7. Environment and Sustainability - Understand the impact of professional engineering solutions in societal and environmental contexts and demonstrate knowledge of and need for sustainable development;
8. Ethics - Apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice;
9. Communication - Communicate effectively on complex engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions;
10. Individual and Team Work - Demonstrate knowledge and understanding of engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments;
11. Life-long Learning - Recognise the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest

context of technological change. In the preceding sections, the present work will highlight how the relevant assessments and module learning outcomes (LOs) are mapped to the POs above.

Programme Outcome 3 is directly related to capstone project modules. The fact that an entire PO is dedicated to the design and development of solutions reflects the trend of engineering education progressing into the "learning by doing" pedagogy, in which students actively engage in designing and developing outcomes. Capstone project modules can also take the students from the classroom into the real world by exposing them to industry practices by the best engineers in the field. Lave [4] stated that capstone project modules aid the student in making the transition from a student based environment to that of a professional engineering environment. Leifer [5] defines a capstone project as a challenge oriented, project organized learning activity that produces a product for an external stakeholder.

The present paper will provide a more detailed look into the structure of a capstone project module named Mechanical Engineering Group Project 1. The details of the outcomes required by the students as well as how these outcomes are measured would also be detailed. The goal of the investigation was to show that through the innovative delivery methods involved in amalgamating practical experience with theory based information resulted in a significant improvement of the students module learning outcome (LOs) attainment compared to how the module was run differently in previous years.

Mechanical Engineering Group Project 1 is offered to all Mechanical Engineering (ME) third year first semester students. This module is compulsory and carries three (3) credit hours out of the student's total credit hours of 126.

This module is pre-requisite for Mechanical Engineering Group Project 2. For contextual purposes, insight would also be given into the successor of this module – Mechanical Engineering Group Project 2. However, this paper focuses on the evaluation of outcomes from Mechanical Engineering Group Project 1.

The module aims to introduce students to hands-on projects with a focus on Mechanical Engineering. Students are required to form and work in groups. Each group reports to the coordinator with whom they must consult regarding the practical aspects of the project and the writing of the documentation.

The assessment of this subject is based on:

- Project Proposal
  Mark: 10% of overall assessment
  Type of Assessment: Group
- Portfolio
  Mark: 30% of overall assessment
  Type of Assessment: Individual
- Project Report
  Mark: 20% of overall assessment
  Type of Assessment: Individual
- Final Presentation & Artefact Assessment
  Mark: 40% of the overall assessment

Type of Assessment: 30% Individual and 10% Group respectively.

Mechanical Engineering Group Project 2 is a project-based module offered for all Mechanical Engineering (ME) third year second semester students. This module is compulsory and carries three (3) credit hours out of student's total credit hours. This module is a continuation for Mechanical Engineering Group Project 1. The module aims to introduce students to hands-on projects with more focus on Mechanical Engineering aspect. Students are required to continue working in the groups formed during Mechanical Engineering Group Project 1.

The assessment of this module is based on:

- Technical Operations and Maintenance Manual
  Mark: 60% of overall assessment
  Type of Assessment: Individual
- Artefact Assessment
  Mark: 20% of the overall assessment
  Type of Assessment: Group
- Logbook
  Mark: 15% of the overall assessment
  Type of Assessment: Individual
- Peer Assessment and Feedback Survey
  Mark: 5% of the overall assessment
  Type of Assessment: Individual

In order to ensure that each assessment is validated through some form of measurement and to reduce the subjectivity of the assessors, rubrics were created. It should be noted that the rubrics also take into consideration the qualitative nature of the assessment. This is a requirement of the accreditation body.

It should also be noted that the intention in this write-up is not to describe it from the normative approach. The assessments and the delivery of the module are rooted in an Outcome Based Education (OBE) model.

## 2.Methodology

Taking into account the need to develop a capstone project module to encapsulate the requirement of the programmes stakeholders, the School of Engineering at Taylor's University in Malaysia developed a year-long capstone, in two modules. The capstone was developed with CDIO$^{TM}$ initiative (Conceive, Design, Implement and Operate) in mind – where the first module – called Mechanical Engineering Group Project 1 (MEGP1) was intended to focus on students achieving outcomes related to "conceive" while its successor Mechanical Engineering Group Project 2 (MEGP2) was intended to focus on students achieving outcomes related to "design, implement and operate". The CDIO syllabus is divided into 4 categories as follows [6].

1. Technical Knowledge and Reasoning: defines the mathematical, scientific and technical knowledge that an engineering graduate should have developed.

2. Personal and Professional Skills and Attributes: deals with individual skills, including challenge resolving, ability to think creatively, critically and systematically and professional ethics.
3. Interpersonal Skills, Teamwork and Communication: skills that are needed in order to be able to work in groups and communicate effectively.
4. Conceiving, Designing, Implementing and Operating Systems in the Enterprise, Societal and Environmental Context: about what engineers do, that is, conceive-design-implement-operate products, processes and systems within the associated context.

The LOs of MEGP1 are as follows.

**Table 1. Learning Outcomes (LOs) of MEGP1.**

| LOs | LO Statements |
|---|---|
| LO1 | Analyse and identify root causes of a given challenge |
| LO2 | Justify proposals and suggestions based on sound technical knowledge |
| LO2 | Develop effective solutions |
| LO3 | Explain the implication of design on manufacturability, testability, usability, ease of maintenance and sustainability |
| LO4 | Evaluate design using appropriate method/methods |
| LO5 | Document one's work diligently and thoroughly |
| LO6 | Evaluate design using appropriate method/methods |

The LOs are in turn mapped to the relevant assessments as follows.

**Table 2. The Assessment-Learning Outcome Mapping for MEGP1.**

| **Distribution** | (%) | LO 1 | LO 2 | LO 3 | LO 4 | LO 5 | LO 6 |
|---|---|---|---|---|---|---|---|
| Logbook | 30 | X | X | X | X | X | X |
| Project Proposal | 10 | X | X | X | | | |
| Final Report | 20 | X | X | X | X | X | X |
| Final Presentation | 30 | X | X | X | X | X | |
| Artefact Assessment | 10 | X | X | X | X | X | |
| Total | 100 | | | | | | |

The synopsis of MEGP1 is as follows: the students will work in teams to solve an engineering challenge, analyse an engineering failure or build an engineering product. Assessment for this subject is in two parts: group and individual. The individual component is assessed through student portfolios, final report and presentation, while the group effort is based on project proposal.

MEGP1's inaugural offering was in September 2011. A project based module with CDIO as its main ingredient served as the only project based experience for the School's students in Year 3 Semester 1 of a 4-year Taylor's University engineering degree programme. Students were free to consult with the academic staff of the School to solicit projects on which they could work on for MEGP1 and MEGP2. At the end of the semester in December 2011, students had completed their projects with relevant staff and were able to show that they had conceived a significant project worthy of a senior project based learning module. Teams were no larger than six students per team with one academic supervisor. The projects and the students along with their supervisors then flowed into MEGP2, which was in full operation in the semester that succeeded the September 2011 semester – April 2012. In MEGP2 students worked on providing a detailed design of their chosen concept, implementation plans for how to fabricate and test their product as well as crafting an operations manual for their product.

The LOs of MEGP2 are as follows.

**Table 3. Learning Outcomes (LOs) of MEGP2.**

| LOs | LO Statements |
|---|---|
| LO1 | Build a prototype based on design |
| LO2 | Validate and verify the functionality of prototype against design |
| LO3 | Evaluate design based on performance, cost and sustainability, and propose improvements |
| LO4 | Create an operation manual or procedure |
| LO5 | Perform project closure |

The LOs are in turn mapped to the relevant assessments as follows.

**Table 4. The Assessment-Learning Outcome Mapping for MEGP2.**

| Distribution | (%) | LO 1 | LO 2 | LO 3 | LO 4 | LO 5 |
|---|---|---|---|---|---|---|
| Detail Design | 15 | X | X | | | |
| Technical Report | 20 | X | X | X | | X |
| Artefact Assessment | 15 | X | | | | |
| Final Presentation | 15 | | X | X | | |
| Operation Manual | 15 | | | | X | |
| Portfolio | 20 | X | X | X | X | X |
| Total | 20 | X | X | X | X | X |

Both MEGP1 and MEGP2 consist of three (3) credit hours respectively. In essence, this is defined as an hour's lecture and four (4) hours worth of supervised discussion sessions (where the guest lectures were also delivered in these discussion slots). The supervision scope was clearly defined through a rubric that captured the areas that were to be assessed in reference to the prescribed learning outcomes. The resources that were made available to the student groups, including access to academic and laboratory staff, also included the relevant materials and consumables needed to produce their HPV.

At this point in time, the School was heavily involved in its Outcome Based Education (OBE) implementation. Part of the OBE process in the School was to use relevant data and evidences which are able to describe the LO achievement of an individual student and to use such data to further improve the module.

This was accomplished in the spirit of Continual Quality Improvement (CQI). CQI as practiced by the School, derives its origins from the Plan-Do-Check-Act

(PDCA) cycle. The Chartered Quality Institute defines quality as having both attributes in innovation and care [7]. The School has placed considerable effort in developing a sustainable process that promotes CQI and this is further detailed.

The ESAT tool was initially developed as detailed in Gamboa and Namasivayam [9][10]. In essence the tool is able to calculate the LO attainment per student using the following equation.

$$\text{LO attainment} = \frac{\text{Student Raw Mark}}{\text{Maximum Raw Mark}} \text{ X Normalized LO Mark} \quad (1)$$

where,

| | |
|---|---|
| LO attainment | the specific LO attainment of an individual student |
| Student raw mark | the raw mark a student obtains for a particular assessment e.g. 8/10 for an assignment |
| Maximum raw mark | the maximum raw mark a student can obtain for a particular assessment e.g. 10/10 |
| Normalized LO Mark | the normalized maximum mark a student can obtain with respect to an LO which is mapped to a particular assessment |

ESAT is also able to calculate the PO attainment of a student. This would be possible since the LOs of a module are directly mapped to the POs in a programme. It should be noted that the POs for the Taylor's programme differs from that highlighted in the introduction, however is developed within its essence and are mapped to each other. The PO attainment per student is calculated using the following equation.

$$\text{PO attainment} = \sum \text{Fractional LO attainment} \quad (2)$$

where,

| | |
|---|---|
| $\sum$ Fractional LO attainment | Is the sum of the fractional LO attainment mapped to the corresponding PO, e.g. LO 1 may be mapped to PO 1 and PO 2, hence the PO 1 attainment would be equal to half of the LO 1 attainment. |

In addition to ESAT, the following was also made use of.

- The Module's Examiners Report. This report provides a breakdown of the grades obtained by each student in a module.
- The Module's Course Evaluation Survey. This survey highlights the strengths and weaknesses of the module and its lecturer as seen by the students themselves.

Students were deemed to have attained an LO or a PO if the following conditions (key performance indicators – KPIs) were satisfied.

KPI 1: 60% of the students attain 60% of the LO attainment score – this is defined by 60% of the students who sit for the module must achieve a certain score for relevant assessments mapped to certain LOs, such that the LO attainment score (For each LO) is ≥ 60%.

KPI 2: 60% of the students attain 60% of the PO attainment score – this is defined by 60% of the students who sit for the module must achieve a certain score for relevant assessments mapped to certain POs, such that the PO attainment score (For each PO) is ≥ 60%

## 3. Results and Discussion

### 3.1. First cycle – Completion of September 2011 Semester MEGP1 and April 2012 Semester MEGP2

The culmination of running MEGP1 and MEGP2 resulted in a total of ten projects and was an enriching experience for both the students and the supervisors involved. Figure 1 below illustrates one of the projects a team of students worked on – the Taylor's Racing Team (TRT) Racing Car.


**Fig. 1. TRT race car.**

It was found that for MEGP1 the module did not meet the Schools 1st key performance indicator (KPI) for a module, i.e. to have 60% of the students achieving all LOs. Note that an LO is considered achieved if a student scores 60% of the LO attainment mark (as calculated using Eqn (1) above). Figure 2 illustrates the results where only 54% of the students were found to achieve all LOs.

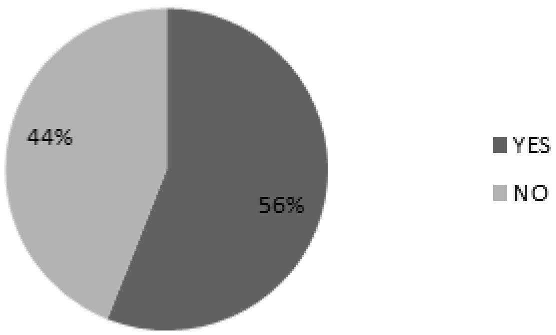


**Fig. 2. Number of students (%) achieving all LOs in MEGP1.**

It was also found that for MEGP1, the module was unable to meet the Schools 2nd KPI for a module i.e. to have 60% of the students achieving each LO. This result can be seen in Figure 3. From the figure, more than 60% of the students were able to achieve LOs 1 through to 5, however LO 6 was only achieved by 56.5% of the students. This LO was associated with the students ability in documenting their work. Based on this result, it would be necessary to identify how we might better assist the students in documenting their work to enhance LO 6 attainment in the future.

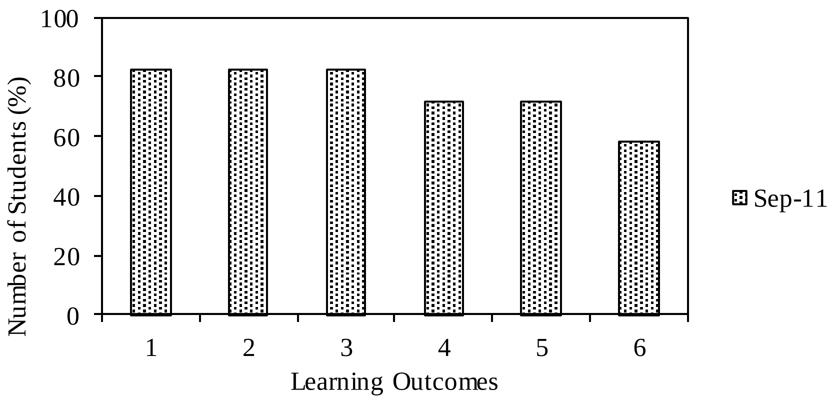


**Fig. 3. Number of Students (%) Achieving Each LO in MEGP1.**

For MEGP2 77% of the students were able to achieve all LOs. Thus for MEGP2, this module met the Schools 1st KPI and the result is illustrated in Figure 4.

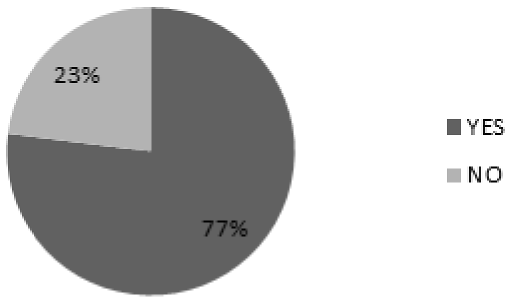


**Fig. 4. Number of Students (%) Achieving all LOs in MEGP2.**

For MEGP2, the module met the Schools 2nd KPI where more than 60% of the students were able to achieve each LO as illustrated in Fig. 5.

As per the Schools CQI process, detailed in Figure 6, the module lecturer of MEGP1 and MEGP2 implemented the entire CQI process and a CQI action plan was produced for the second cycle which was implemented in the September

2012 Semester offering of MEGP1 and the April 2013 Semester offering of MEGP2.

The goal of the CQI action plan was to meet and exceed the Schools 1st and 2nd KPIs in the 2nd cycle of operation of MEGP1 and MEGP2 which were both being offered for the second time in September 2012 and April 2013 respectively.

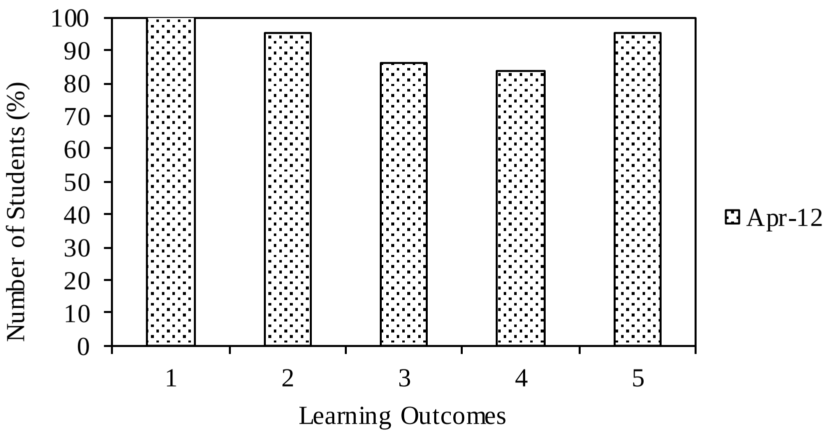


**Fig. 5. Number of Students (%) Achieving Each LO in MEGP2.**

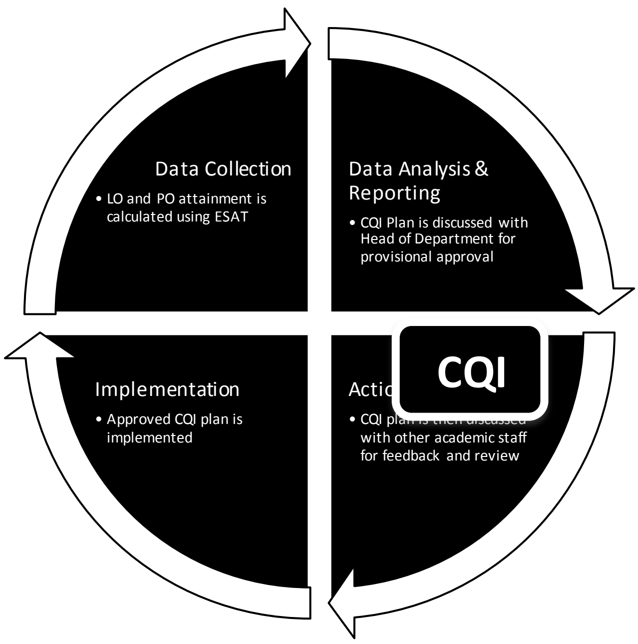


**Fig. 6. Schools Continual Quality Improvement (CQI) Process.**

The following CQI action plan was suggested.

**Table 5. CQI Action Plan for MEGP1 and MEGP2.**

| No. | CQI Action Point (What? and How?) | Source of CQI Action Point (Why?) | Implementation (When?) |
|---|---|---|---|
| 1 | The level of assessment (in terms of Blooms Taxonomy) would need to match more closely to the prescribed LOs. | Assessment components needed to be aligned to the LOs. | MEGP1 and MEGP2 in September 2012 and April 2013 respectively. |
| 2 | Effort would be made to ensure that students are exposed to industrial practices relating to CDIO - this would be accomplished by inviting guest lecturers who are registered Professional or Chartered Engineers. | To amalgamate industry practice with theory. | MEGP1 and MEGP2 in September 2012 and April 2013 respectively. |
| 3 | Effort would also be made to engage students on a more regular basis and to provide critical engineering analysis on all assessments. | Based on feedback from the course evaluation survey. | MEGP1 and MEGP2 in September 2012 and April 2013 respectively. |
| 4 | To change the way students would document their work to enhance the achievement of LO 6 in MEGP1. | To ensure that LO 6 of MEGP1 meets the Schools 1st KPI. | MEGP1 in April 2013. |

## 3.2. Second Cycle – Completion of September 2012 Semester MEGP1 and Implementation of April 2013 Semester MEGP2

In order to implement the prescribed CQI action plan it was decided that the previous method of allowing students to work with individual supervisors on separate projects for the duration of MEGP1 and MEGP2 was to be eliminated due to the non-uniformity in supervision techniques. The decision was made to move from individual projects to a single project, which was a design challenge all students would share. Thus, the module adopted the American Society of Mechanical Engineers (ASME) Human Powered Vehicle (HPV) Challenge. The information made available to the public with respect to the HPV challenge served as additional references to the students who were taking the module.

For MEGP1, the “conceive” part of the capstone project module, students were advised that they would need to develop a conceptual model on an assembly plant which would ultimately be used to assemble and in some aspects manufacture their HPV. In order to accomplish this, students would need to make use of their existing theoretical knowledge to conceive a HPV design and thus begin work on proposing a viable business model of conceiving, designing, implementing and operating an assembly plant.

As the capstone project needed to have significant input from industry, the teams would need to be exposed to the more commonly used industry practices and implement them in their conceptual model for the assembly plant. Specifically, the following key industry practices were highlighted.

- Safety, Health and the Environment
- Sustainability
- Engineering Ethics
- Lean Manufacturing
- Project Management

The key areas of practice were identified from the outcomes as highlighted by EAC as well as through various stakeholder input (industry experts). Each of the above areas of interest would be delivered in the form of a weekly lecture by either a Professional or Chartered Engineer with at least ten (10) years of experience in their respective fields in industry. This was accomplished for all of the above areas with the exception of Project Management where a Project Manager with more than ten (10) years of experience and possessed a Project Management Professional (PMP©) certification had delivered the lecture. From each of these lectures, the experts shared relevant industry standards and how they were implemented in practice. The students would then take home one tool or technique that could be directly applied to their task in MEGP1 (in this case their assembly plant).

**Table 6. List of Industry Specific Lectures.**

| Areas of Expertise | Lecture Topic | Tool Adopted | Industry Expert Bio |
|---|---|---|---|
| Safety, Health and the Environment | Process Safety Management | Bow Tie Hazard Analysis | Professional Engineer registered with the Californian Board of Engineers, United States of America |
| Sustainability | Sustainability in Engineering | The Malaysian Green Building Index | Professional Engineer registered with the Board of Engineers, Malaysia |
| Engineering Ethics | Engineering Ethics | The Route to Becoming a Professional Engineer | Professional Engineer registered with the Board of Engineers, |

| | | | |
|---|---|---|---|
| | | | Malaysia and Chartered Engineer registered with the Engineering Council, United Kingdom |
| Lean Manufacturing | Lean Manufacturing | The Quality House | Chartered Engineer registered with the Engineering Council, United Kingdom |
| Project Management | Project Management Tools and Techniques | Earned Value Management | Project Management Professional certified by the Project Management Institute |

Another key feature of the newly operational MEGP1 module is the logbook assessment component. This was implemented to cater for the fact that in the last cycle, LO 6 for MEGP1 failed to meet the Schools 2nd KPI. Since the logbook component was directly mapped to LO 6, a new method of assessing students for this LO was implemented as follows.

In order to achieve the Professional Engineering status in Malaysia, engineering graduates are to firstly register with BEM and become a graduate member of the Institution of Engineers Malaysia (IEM). They are then placed onto a mentoring scheme and are requested to keep a detailed logbook on their professional development for three (3) years. Upon the elapse of this time, the logbook together with the relevant documents and application forms are submit to IEM for further verification and approval on whether a candidate is ready to be called in for an oral interview, which if they pass are granted the status of a Professional Engineer.

In order to expose the students to this process, part of the assessment requires them to maintain a detailed individual logbook and this document is similar to that used by young engineers in collating evidences for their future Professional Engineering application (as described above). The lectures highlighted in Table 5 above also serve as professional development for the students.

Students were also taken to an industrial visit to an assembly plant of a Japanese car manufacturer to expose them to its actual day-to-day operations on the ground.

The amalgamation in all of the experiences which the students were exposed to (industry lectures and visit) culminated in them applying and evaluating industry based tools to their tasks in MEGP1. Some of these tools are highlighted in the subsequent text.

Figure 7 illustrates the application of the Bow-Tie Hazard Analysis. This analysis provides an evaluation of associated hazards, how it is caused as well as to what controls are to be implemented for each hazard. The students applied this tool to relevant sections in their assembly plant model.

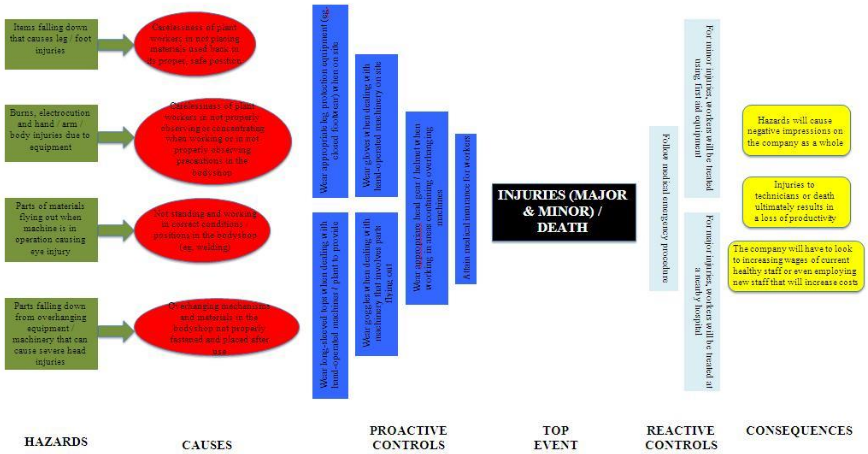


**Fig. 7. Bow Tie Hazard Analysis.**

The students also adopted the Quality House, a tool used to ascertain the demand of the customer and incorporate them into the product. This would in turn drive the final design of their HPV and the manufacturing processes employed to produce their HPV. The tool which one of the teams produced is illustrated in Fig. 8.

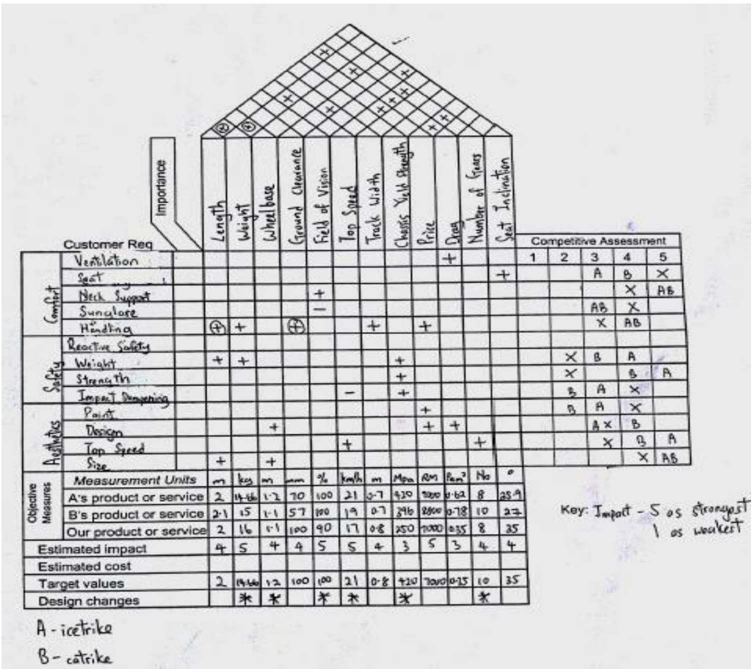


**Fig. 8. The Quality House.**

Another tool which was adopted by the students came from the area of Project Management. This was the Earned Value Analysis or Earned Value Management (EVM) tool. EVM is a powerful tool used by project managers who use it to assist them in controlling and monitoring the progress of their project during the project execution stage. Applied correctly, EVM could be used to diagnose the healthiness of a project, i.e. whether it is behind or ahead of schedule as well as being over or under budget. This is done by calculating the Planned Value (PV – the initial value of a task in a project), the Earned Value (EV – the amount earned by completing a task in a project at a specified time) and the Actual Cost (AC). An example of EVM as performed by one of the teams from MEGP1 is illustrated in Figure 9.

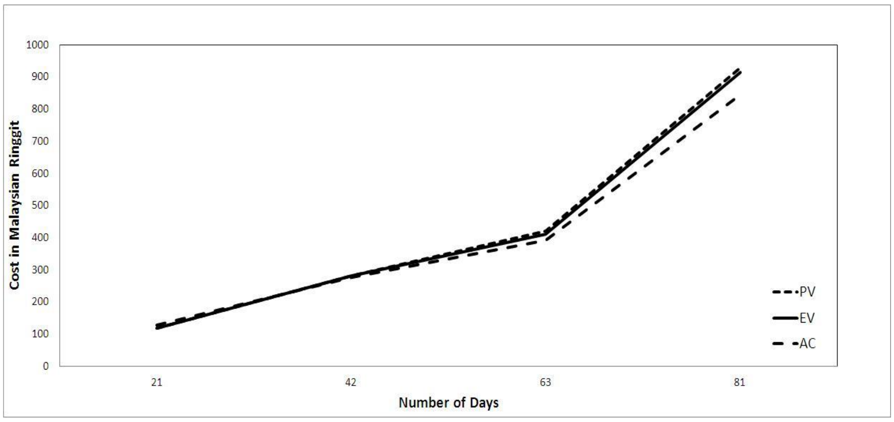


**Fig. 9. Earned Value Management.**

Upon implementation of the CQI action plan and the changes made in MEGP1, the ESAT result showed a marked improvement over the previous. The results satisfied both the 1st and 2nd School's KPIs. In terms of the 1st KPI, it was found that 94% of the students have achieved all LOs. This is illustrated in Figure 10.

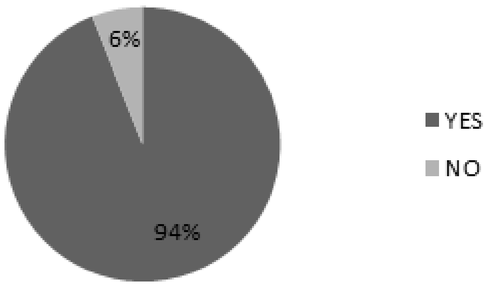


**Fig. 10. Number of Students (%) Achieving all LOs in MEGP1.**

In terms of meeting the 2nd KPI, LOs 1 through to 5 achieved a score of 100% while LO 6 achieved a score of 94.1%. This is illustrated in Figure 11.

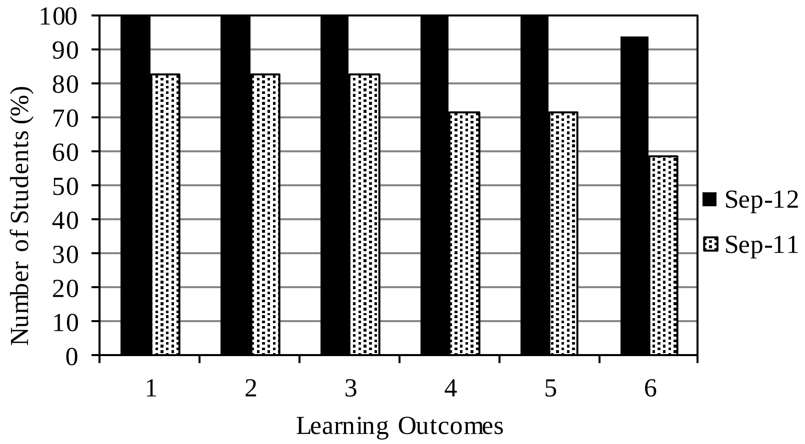


**Fig. 11. Number of Students (%) Achieving Each LO in MEGP1 – Comparison of September 2011 and September 2012 ESAT Results.**

In addition to the marked improvements shown in the ESAT results, the course evaluation survey also showed an increase. The questions in the survey are listed below while the results of the survey are illustrated in Figure 12.

1. The outline and expectations for this course as supplied by the lecturer were clear.
2. The lessons were organised and prepared.
3. The lecturer was knowledgeable about the course content.
4. The course content was effectively presented.
5. Opportunities were provided for student participation.
6. The homework and classroom assignments were helpful.
7. The textbooks and/or recommended materials were useful.
8. The lecturer was available for consultation and was helpful.
9. The assessment was fair.
10. This course met my needs and goals for future study and/or employment.

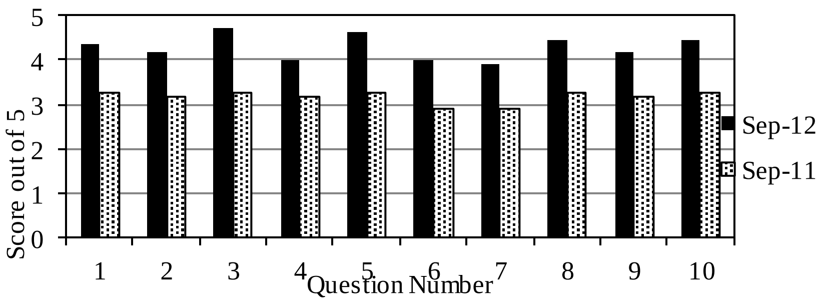


**Fig. 12. Course Evaluation Survey Results for MEGP1 – Comparison of September 2011 and September 2012 Results.**

In summary the following changes were implemented in MEGP1.

- One specific project was given as the task, i.e. to Conceive, Design, Implement and Operate a Human Powered Vehicle.
- One supervisor (who was the module coordinator) was identified.
- External-industry based Chartered and Professional Engineers provided guest lectures on key areas related to Engineering.
- A large focus on 5 key areas, namely Sustainability, Safety, Project Management, Ethics and Lean Manufacturing.

In order to emulate the same enhancement and to exceed the expectations of the LO achievements and course evaluation survey results, similar plans for MEGP2 are to be implemented. Specifically the following has been planned for April 2013.

- Industry specific lectures will be held to adopt at least one industrial tool or technique to apply in the module. The lectures will focus around technical design, maintenance and operation.
- The adoption of ASME's HPV Design Criteria as a marking rubric for the design component of the module will be implemented.
- Industry based engineering experts will be invited to assess the teams at the end of the semester.
- An in-house racing competition is being planned upon the successful completion of all designs.

## 4. Conclusions

The work completed in the present investigation has shown that by inculcating practical experience, through the delivery of specific industry applications by industry experts, students were able to apply these techniques to their project. The LO achievement of all students also increased. Further, students were more satisfied with this method of delivery, based on the course evaluation survey results.

Based on the ESAT results for MEGP1, there was an increase of 40% in terms of the number of students who have achieved all LOs. It was also found that 100% of the students achieved five out of the six LOs. In addition to the ESAT results, the course evaluation survey for MEGP1 showed an improvement of 35% (overall average) increase on the mean score of the survey questions. The data suggests that the implementation of the CQI action plans in the September 2012 semester were the direct cause of these improvements.

As one of the main CQI actions carried out by the School for MEGP1 was to amalgamate one industry tool from each of the 5 key industry areas into the curriculum resulted in an improvement on the LO attainment as well as the overall student satisfaction of the module.

It is envisaged that, if similar CQI actions are carried out for MEGP2, an enhancement would also be observed in the upcoming April 2013 semester.

By amalgamating industry practice with theory, students were exposed to a variety of tools and techniques used by industry experts – this at the very minimum would have increased their level of awareness on how an engineer who would employ CDIO would apply such tools.

The demand which has been created by industry in requiring engineers who have the ability to conceive, design, implement and operate a specific engineering system has enabled universities to develop capstone projects in many undergraduate programmes. The appropriateness and applicability of such modules are direct; in the sense that it is being driven by requirements of the industry and regulatory/accrediting bodies. In our experience, there is a lack of holistic engineering capstone courses that can support these needs. This paper provides one example of how this might be done effectively through our experience of amalgamating industry practices, technical as well as soft skills into the capstone courses. This capstone demonstrates the positive results of delivering a capstone where outcomes are linked with industry.

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