THE AMALGAMATION OF INDUSTRY PRACTICES IN AN ENGINEERING CAPSTONE PROJECT

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ABSTRACT

A capstone project is introduced to enable the holistic attainment of engineering knowledge by engineering undergraduate students. Integrating project-based-learning and the industrial practices, a capstone project can play an important role in acquiring skills necessary for future employment as well as obtaining professional or chartered engineer status, which is a legal requirement in some countries. A carefully selected capstone project provides the students 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 use of a CDIO process that is grounded in both theoretical academic knowledge and practical industrial best practices. This paper presents the design and implementation of such a capstone project module, incorporating learning sessions from professional engineers in the five (5) key areas of industry practice highlighted above and how these has contributed to significantly enhancing the learning outcome attainment of engineering undergraduates who have experienced the module.

KEYWORDS

Capstone projects, industrial practice, outcome-based-education

INTRODUCTION

The current state of engineering education is progressing swiftly into the direction of inculcating practical experience in a theoretically based environment. This is demanded by the stakeholders (namely employers) in their pursuit of well-prepared graduates. The most obvious way in ensuring that graduates are ready to add value 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. One of the efficient way to handle this would be to create a capstone project module which is able to amalgamate industry based experience with theory. Hotaling et al. [1] indicated that in order for engineering students to excel and advance in industry, it is the role of the university in ensuring that the associated courses must reflect as many industry based challenges as it is realistically able to do. They also stated that the objective of a capstone project module is to infuse practical experience into current academic curriculum employing 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 who are members of the Washington Accord (Malaysia being a signatory) and more importantly is 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 this day and age would need to cover a variety of modules that are aimed at producing competent graduate engineers who can excel in both the technical and social areas. Bordogna et al. [2] argued that the main focus of engineering education should be to develop the students' capabilities in integrating, analysing, innovating, synthesising and understanding challenges in a contextual manner – this is in essence what a student should be capable of achieving upon graduation.

EAC currently preaches eleven (11) key outcomes an engineering student is expected to attain upon graduation – thus defined as the Programme Outcomes (POs). Of specific interest to this paper, is PO that reads as follows: *"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."* Achievement of this particular PO is only imaginable through project-based learning and particularly capstone project modules. Carefully constructed capstone project modules can take the students from lecture halls into the real world by exposing them to industry practices by the best engineers in the field.

This paper offers a detailed look into the structure of a capstone project module entitled – Mechanical Engineering Group Project 1 offered at the third year of a mechanical engineering programme. The details of the outcomes required by the students as well as how these outcomes are measured are explained. The goal of the investigation is 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 in previous years. Insight would also be given into the successor of this module – Mechanical Engineering Group Project 2 and this module will envisage emulating the same success as its predecessor. The research question of the investigation is to find out whether there is a perceived enhancement of student learning through the amalgamation of industry practices in a capstone project module. This forms the central issue of the present work.

MODULE STRUCTURE

To address the requirements of the programme's stakeholders, the School of Engineering at Taylor's University in Malaysia designed two capstone project modules offered over two semesters of the third year of a mechanical engineering programme. These modules were developed following the CDIO framework. The first module is called Mechanical Engineering Group Project 1 (MEGP1) and aimed at achieving outcomes related to "conceiving" a sophisticated mechanical system, while the second module, Mechanical Engineering Group Project 2 (MEGP2), is aimed at achieving outcomes related to "designing, implementing and operating" that mechanical system.

MEGP1's inaugural offering was in September 2011. 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 on how to fabricate and test their product as well as crafting an operations manual for their product.

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 attainment 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). Upon completion of both the MEGP1 and MEGP2 modules, the relevant assessments were collated and analysed using the Schools End of Semester Assessment Tool (ESAT). This tool is able to calculate the individual LO and PO attainment of a student in a particular module and programme. The ESAT tool was initially developed as detailed in Gamboa and Namasivayam [5]. In essence the tool is able to calculate the LO attainment per student using the following equation.

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

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
Normalised LO Mark	the normalized maximum mark a student can obtain with respect to an LO which is mapped to a particular assessment

RESULTS AND DISCUSSION

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 shows one of the projects a team of students worked on, to conceive, design, build and race a arcing 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 attaining all LOs. It was found that only 54% of the students attained all LOs. Note that an LO is considered attained if a student scores 60% of the LO attainment mark (as calculated using Eqn (1) above). It was also observed that this module was unable to meet the Schools 2nd KPI for a module i.e. to have 60% of the students attaining each LO. This result can be seen in Figure 2 where more than 60% of the students were able to attain LOs 1 through to 5, however LO 6 was only attained by 56.5% of the students. This LO was associated with the students' ability to document their work. Based on these results, it would be necessary to come up with a better way to assist the students in documenting their work to enhance the LO 6 attainment in the future. It is believed that the inability in achieving the relevant KPIs was due to the non-streamlining nature of the projects as well as its assessment scheme.

Figure 1. Taylor's Racing Team (TRT) Race Car

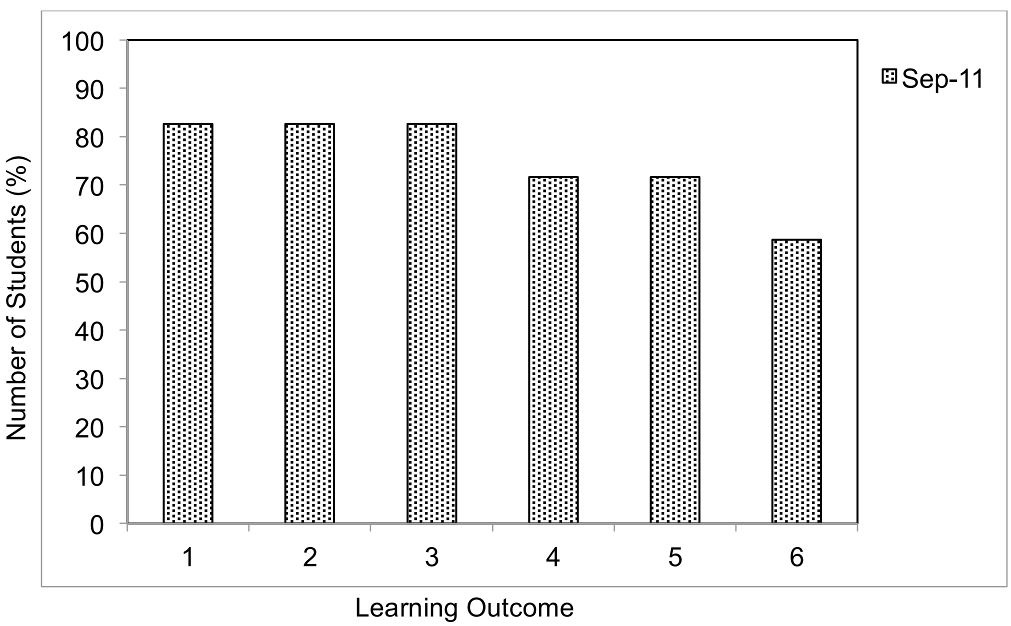

Figure 2. Number of Students (%) Attaining Each LO in MEGP1

For MEGP2, 77% of the students were able to attain all LOs. Thus, this module met the Schools 1st KPI. The module also met the Schools 2nd KPI where more than 60% of the students were able to attain each LO as illustrated in Figure 3.

In the spirit of CQI, the module lecturer of MEGP1 and MEGP2 respectively produced a CQI action plan for the second cycle which was implemented in the September 2012 Semester offering of MEGP1 and the April 2013 Semester offering of MEGP2.

The following CQI action plan was suggested.

- The level of assessment (in terms of Blooms Taxonomy) would need to match more closely to the prescribed LOs.
- 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.
- Effort would also be made to engage students on a more regular basis and to provide critical engineering analysis on all assessments.
- To change the way students would document their work to enhance the attainment of LO 6 in MEGP1.

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.

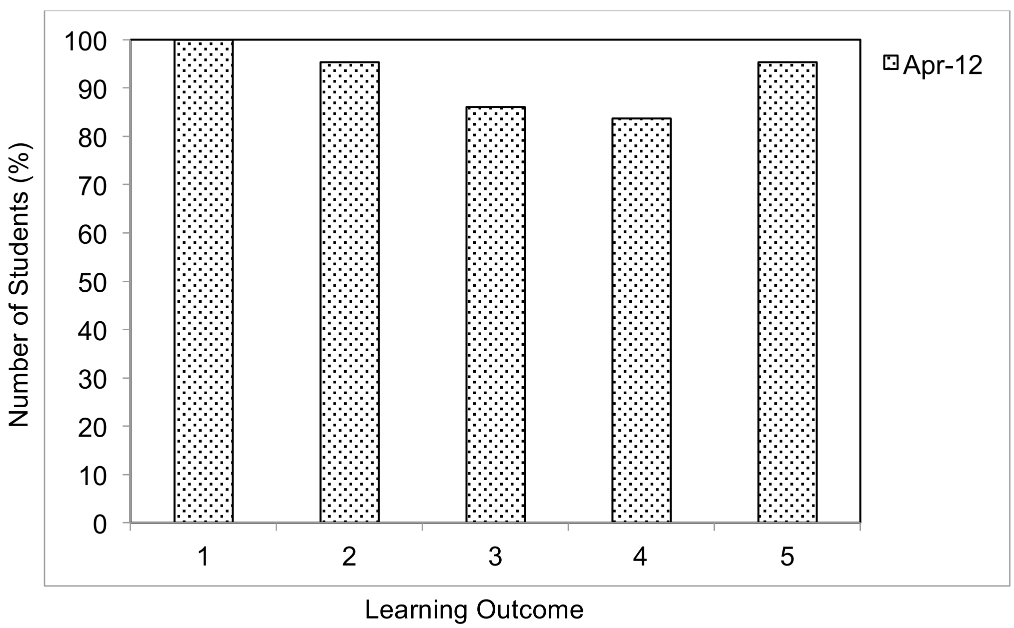

Figure 3. Number of Students (%) Attaining Each LO in MEGP2

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 address a specific project which was a design challenge in itself. 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 of 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 their industry standards and how it was implemented in their areas of expertise and as practiced by other engineers in industry. The students would then take home one tool or technique which would be directly applied to their task in MEGP1 (in this case their assembly plant). The tools adopted are listed as follows.

- Bow Tie Hazard Analysis – adopted from the “Safety, Health and the Environment” lecture.
- The Malaysian Green Building Index – adopted from the “Sustainability” lecture.
- Becoming a Professional Engineer – adopted from the “Engineering Ethics” lecture.
- The Quality House – adopted from the “Lean Manufacturing” lecture.
- Earned Value Management – adopted from the “Project Management” lecture.

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. It should be noted that industry experts were appointed from the School's Industrial Advisory Panel (IAP) and the delivery of their respective topics were streamlined with the LOs of the module by having a discussion on the content of their lectures with the module coordinator prior to the implementation of the lecture. The topics were also chosen based on feedback received from the IAP on key industry areas which they felt engineering graduates would need to be exposed to.

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 awarded the status of a professional engineer.

In order to expose the students to the process above, 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 amalgamation of all the experiences which the students were exposed to culminated in them applying and evaluating industry based tools to their tasks in MEGP1. An example of one of these tools came from the areas 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 4.

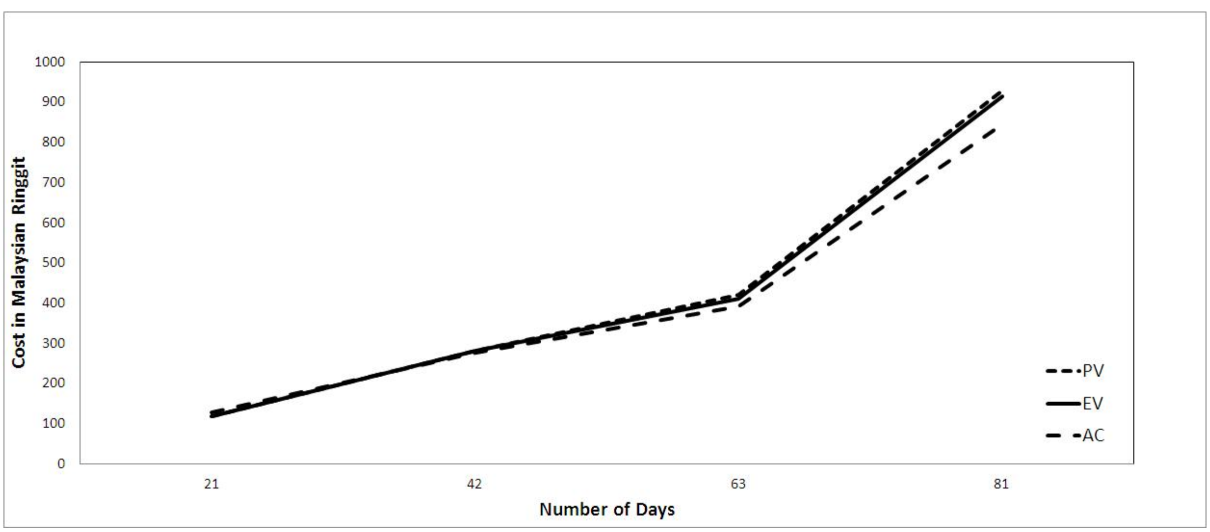

Figure 4. Earned Value Management

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

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 6.

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.

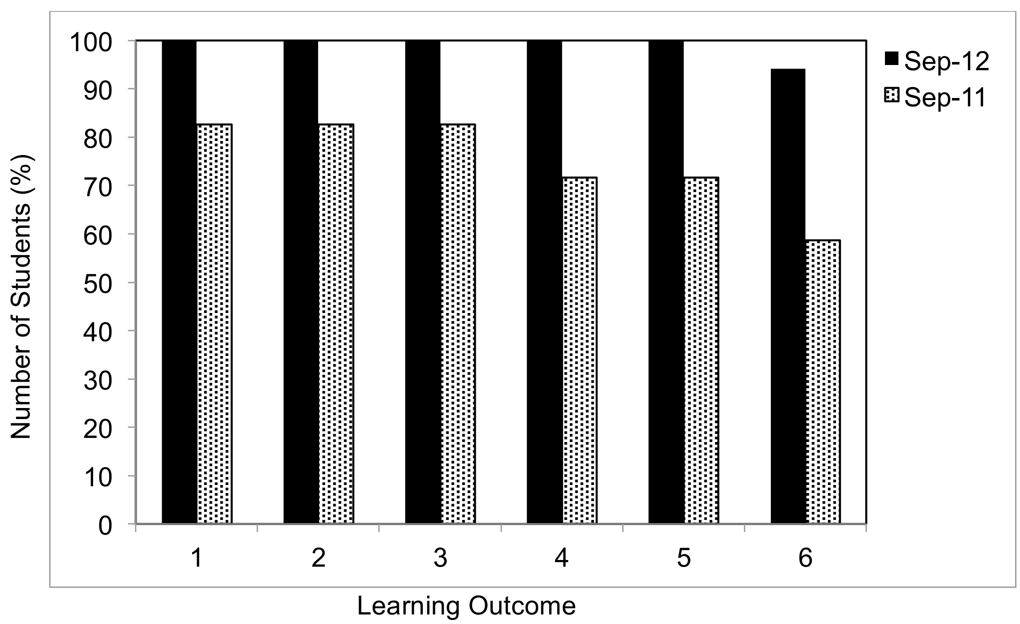

Figure 5. Number of Students (%) Attaining Each LO in MEGP1 – Comparison of September 2011 and September 2012 ESAT Results

In order to emulate the same enhancement and to exceed the expectations of the LO attainments 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 of a prototype design.
- 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.

CONCLUSIONS

A third year capstone project was designed and jointly offered by industry practitioners to expose the students to the best industrial practices. Students exhibited ability to apply the techniques delivered by industry practitioners to their projects and this resulted in an increase in the LO attainment of each student. In addition to that students were more satisfied with this method of delivery based of 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 attained all LOs. The increase was due to the implementation of the CQI action plans in the September 2012 semester, which was recommended based on the results of the September 2011 semester. In addition to the ESAT results, the course evaluation survey for MEGP1 showed an improvement of 35% increase (overall average) on the mean score of the survey questions. 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.

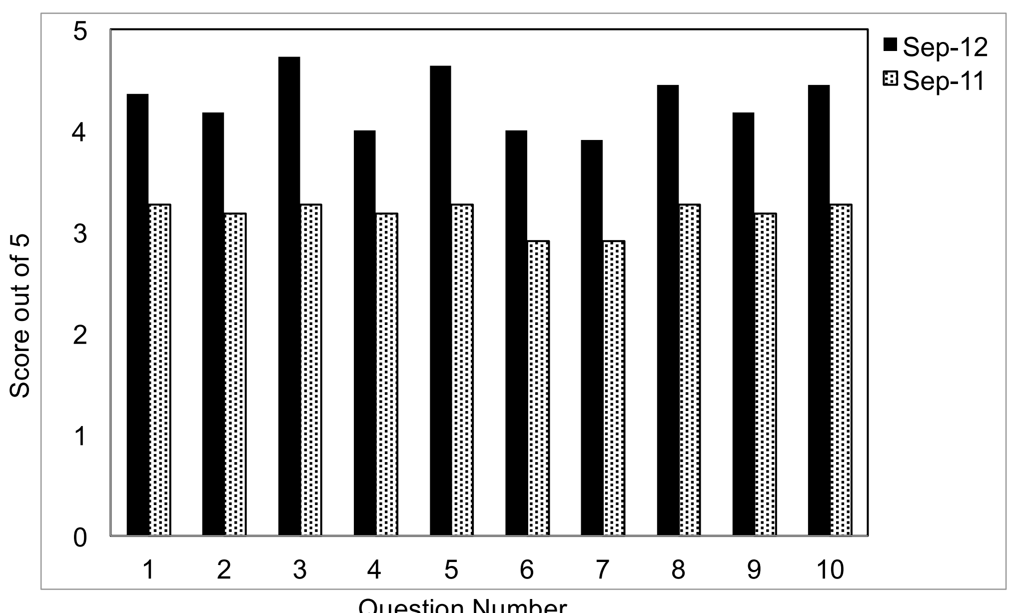

Figure 6. Course Evaluation Survey Results for MEGP1 – Comparison of September 2011and September 2012 Results

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BIOGRAPHICAL INFORMATION

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