Remodelling an Engineering Design Subject to Enhance Students' Learning Outcomes

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Abstract

This paper presents details of remodelling of an engineering design subject to enhance students' learning outcome. The subject is offered for second year mechanical engineering undergraduates in the first semester of the academic year. The basic objective of the subject is to introduce the engineering design practice and to build up the essential skills to carry out open-ended engineering design projects systematically. Before remodelling, the subject had been taught and assessed mainly with the use of techniques normally used for knowledge building subjects. Students were given only limited opportunities to actively engage with the content, peers and the facilitator in-class. Considering the reserved nature of Hong Kong students, the subject was remodelled by incorporating carefully selected active learning methods. The scaffolded knowledge integration framework for instructional design is extensively used for this subject remodelling exercise. The remodelled subject was delivered and the learning outcome achievements were assessed using pre and post survey questionnaires. The survey outcome indicates that the new approach of subject delivery and assessment methods are more effective in achieving intended learning outcomes and well accepted by the students.

Keywords

Engineering design, active learning, scaffolded knowledge integration, workplace skill development

Introduction

In general, Engineering design is a core subject in all the accredited undergraduate engineering programmes. It is essential that every engineering undergraduate acquires adequate engineering design skills as a part of their formal training. For example, ABET criteria for accrediting engineering programmes, specified that the undergraduate engineering programmes must prepare students "... for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic" (Criteria for Accrediting Engineering Programs, 2016 -2017 | ABET 2017). In Mechanical Engineering programme offered by the Hong Kong Polytechnic University (HKPolyU), there are several interconnected subjects at different levels that provide the students with opportunity to acquire essential design skills as stipulated by accreditation bodies; Freshman Seminar for Engineering (Level 1), Engineering Design Fundamentals (Level 2), Multidisciplinary Manufacturing project (Level 3) and Capstone Project (Level 4) (Definitive Programme Document - Bachelor of Engineering (Honours) Degree in Mechanical Engineering 2017). Each subject has a different focus and designed to ensure gradual development of skills. In order to respond to the changing needs of the industry; the content, delivery and assessment methods of these subjects are periodically amended with the inputs from the stakeholders. The goal of the present study is to investigate the effectiveness of a remodelled engineering design subject in HKPolyU Mechanical Engineering programme in achieving intended learning outcomes and developing students' workplace related skills.

It is generally expected that engineering graduates should be equipped with a balance of technical knowledge in addition to the relevant soft skills required in the workplace. Academic programmes in higher education institutions are designed to provide sufficient opportunities for students to develop both essential fundamental technical knowledge and workplace related

soft skills (Cranmer 2006). As students progress through their undergraduate studies, they are expected to learn how to become effective professionals ready to handle the demands associated with his or her job shortly after graduation (Staffan 2010). Employers expect their new recruits to have well developed employability skills, so that they can make an immediate contribution to the workplace when recruited. From employer's point of view, an employable person holds knowledge, skills and characteristics that will make that person useful and valuable for a given job role. Several studies indicate that, there is a considerable mismatch between the competence of the engineering graduates and the demands of the workplace (Cranmer 2006; Saunders and Zuzel 2010; Clarke and Winch 2006; Stiwne and Jungert 2010).

According to views expressed by the employers during department-industry consultative meetings, there exists a similar mismatch between the competence of the mechanical engineering graduates of HKPolyU and the demands of the Hong Kong Industry. Most of the time industry need to make a considerable investment to make them productive by way of providing additional training, mentoring, etc. From the industry point of view, it is desirable to have readily employable engineering graduates who can be made productive with less resources and time investments.

In year 2012, all the universities in Hong Kong introduced new 4 year curriculums for all the programmes as a part of major educational reform, popularly known as 3+3+4 system(Education and Manpower Bureau 2005). The Mechanical Engineering Department of HKPolyU took this opportunity to revamp its curriculum and restructured it with the objective of producing preferred mechanical engineering graduates for 21st century industrial needs.

In Mechanical Engineering curriculum of HKPolyU, 'Engineering Design Fundamentals' is a Level 2 subject. This is the first discipline specific engineering design subject in the curriculum. At Level 1, students get some exposure of the basic elements of engineering design such as

engineering communication with engineering drawing, CAD, technical report writing, team-working and project management with group design projects. The objective of the Level 2 discipline specific subject 'Engineering Design Fundamentals' is to introduce the engineering design practice and to build up the essential skills to carry out open-ended engineering design projects systematically. With the skills developed, it is expected that the students perform well in higher level engineering design subjects and in particular become more confident in carrying out Level 4 Capstone Project independently.

The first cohort of students who have followed the new curriculum, started their final year Capstone project in academic year 2015/16. The authors supervised 5 Capstone project groups collectively and got the first-hand experience of how those 5 groups of students handled the projects from beginning to the end. Most of the students showed that they lack the ability to work independently and were less confident in working with open-ended real life engineering problems. In fact, those are some of the skills that they are expected to develop from Levels 1-3 engineering design related subjects. This experience has triggered us to investigate the shortcomings of 'Engineering Design Fundamentals' subject and remodel it to enhance students learning experience.

Structure of the subject before remodelling

Before remodelling, the 'Engineering Design Fundamental' subject has been designed and taught mainly using techniques normally used for knowledge building subjects. Students were given classroom lectures on selected topics that include introduction to design process, materials and manufacturing processes, design for X, CAD and CAE applications in engineering design, teamwork and ethics. The assessment of students' learning outcomes were done though continuous assessments (50%) and end-of-semester closed-book examination (50%). The continuous assessment consisted of individual homework assignments and a group

mini-project. The key objective of the continuous assessment was to enhance student's comprehension and assimilation of delivered content. The group mini-project provided the opportunity of applying some of the content learned to develop a design solution for a self-selected design need. It also intended for enhancing students' team working, project management and communication skills.

Overall, the subject delivery and assessment methods provided limited opportunities for students to actively engage with the content, peers and the facilitator in-class. However, the knowledge integration subjects should be best learned through experiential learning processes where students get more opportunities to actively engage with learning contents (Bankel et al. 2003), (HALL 2002). Research have shown that in addition to achieving learning objectives related to content, active learning develop the students' abilities in communication, leadership, ethical decision making, and critical thinking (HALL 2002).

Structure of the remodelled subject

With the availability and affordability of mobile computers, smart phones and effective software tools for learning, there are many changes happening in the way we teach and the learning preferences of students(Sergio Martin 2015). In engineering education, problem based learning, project based learning and active learning techniques are widely used with positive impact on learning(Giralt et al. 2000), (Chua et al. 2014). In particular, problem based and project based learning is more effective for engineering design related subjects where students need to integrate the knowledge acquired from other subjects to develop design solutions for identified/given needs.

Learning from the success stories of using active learning techniques in the classroom to enhance students learning experience, the main focus of the remodelling exercise is to introduce relevant and effective active learning opportunities for students to capture key

concepts of the subject. The prior research have shown that the effectiveness of active learning techniques largely depend on student characteristics such as age, communication skills, prior knowledge, cultural values and how the students learn (U.P. Kahangamage 2017), (Chi 2009). Our experience is that Hong Kong students are generally passive in the classroom and lack the skills of engaging in active learning activities. They are more comfortable with passive absorption of knowledge that will help them to perform better in the examinations. Therefore, it is necessary to use appropriate active learning methods by taking into consideration the reserved nature of Hong Kong students.

Furthermore, Engineering Design Fundamental is an important knowledge integration subject where students get to use the knowledge acquired from other subjects to carry out a practical design project. For effective achievement of intended learning outcomes from the subject it is therefore necessary to create a learning environment that facilitate knowledge integration. There is a framework to design learning activities to teach complex concepts called 'the scaffolded knowledge integration, a framework for instructional design' proposed by Linn (Linn 1995). According to this framework, learners construct knowledge by continuously evaluating, refining, and developing ideas they receive from formal training in schools as well as from their everyday lives. The knowledge integration environment (KIE) principles and guidelines developed by Linn (Linn 1995), (Linn 2000) to design learning activities to promote integrated understanding of concepts has been used to develop learning activities of the remodelled subject. According to the KIE principles, an effective design of the integrated learning activity should take into account 4 principles (Linn 2000):

1. Make content accessible
2. Make thinking visible
3. Help students learn from each other

4. Promote lifelong learning

Making use of KIE principles and guidelines we have developed learning activities to promote knowledge integration in the remodelled subject. Each teaching unit now consists of a short introductory lecture, in-class group activity, individual or group short reflective exercise based on the group activity, and self-paced extra learning materials in the learning management system (LMS). The concepts learned in the class are then applied in carrying out a group project where 4-5 students work together to develop a design solution for a given need. The expectation is that the learning activities developed using KIE principles will enhance the learning experience from the remodelled subject by;

Making content accessible by immediately applying the concepts learned in in-class activities that connects the new and existing knowledge

Making thinking visible by interacting with products they use in everyday life and studying the underlying design principles with the use of mind mapping, hand sketching, assembly diagrams, etc.

Helping students learn from each other by working in small groups to solve challenging problems in a constrained environment where they need to communicate, and make use of limited resources (time, manpower) effectively.

Promoting lifelong learning by scaffolding students to practice self-management and reflection while working on the in-class activities and then apply the developed knowledge and skills to complete the group project which is a different challenge.

The assessment method of the students' learning outcome from the subject has also been changed to 100% continuous assessment. Students have to take part in group and individual assessment activities throughout the semester. Therefore, overall assessment of learning

outcome achievement consists of approximately 70% individual performance and 30% group performance.

Methodology

The focus of the study is to assess the effectiveness of the remodelled subject in achieving intended learning outcomes from the subject. The common methods of assessing learning outcomes are through carefully planned assessment activities such as tests, quizzes, assignments, projects, examinations, etc. In this subject also the students' learning outcome achievements have been measured using a combination of those traditional approaches. However, it is difficult or not realistic to use those assessment results to compare between the students' performance before and after remodelling the subject due to many variables involved. For example, the subject was not taught by the same lectures and hence the effect of the teacher cannot be eliminated. As the subject learning outcomes were mainly assessed through a semester long group design project, most of the assessment components rely on the expert judgements of the assessor which is mostly subjective. For this study, therefore, students' self-assessment on their learning achievement before and after the subject delivery was used to assess the effectiveness of the remodelled subject. The assumption is that the one who has experienced the learning process is in a better position to judge the level of his/her own learning achievements. And also it is assumed that 2nd year undergraduate students are mature enough to do self-reflections and make reliable judgements on their own learning achievements.

The learning outcome achievements were assessed using pre and post survey questionnaires given in Appendix that contains 13 questions. The questions were drafted to test the level of achievement of intended learning outcomes of the subject. Table 1 shows the matching of intended learning outcomes of the subject with the survey questions. ILO1 and ILO2 are related

to technical skills required for engineering design practice. ILO3, ILO4 and ILO5 are related to important soft skills required to be an effective design engineer.

Table 1: Survey Questions and matching Intended Learning Outcomes (ILO)

No.	Question	Matching Intended Learning Outcomes (ILO)
1	How would you rate your level of confidence in being able to design a system, component or process to meet identified need?	ILO1: Able to identify, formulate and solve engineering design problems
2	Rate your understanding of the process, tools and techniques that the professional design engineers use to develop new products or systems.	
3	Rate your understanding of different factors need to be considered in a successful engineering design project.	
4	Rate your current awareness of latest trends, developments in engineering product/system design and development.	ILO2: Able to use the techniques, skills and modern engineering tools, including computational tools necessary for engineering design practice
5	Are you aware of techniques, skills, and modern engineering tools including computational tools necessary for engineering design practice?	
6	Rate your skills in using the techniques, modern engineering tools, including computational tools necessary for engineering practice.	
7	How would you rate your understanding of and exposure to various sources of technical information such as textbooks, scientific and technical journals, the library system as a whole, the internet, etc.	ILO3: Able to search for related up-to-date information for decision making and design solution generation in

8	Rate your current ability/skill of searching appropriate information for learning independently using variety of educational media	product design and development
9	Rate your ability to function professionally in a multidisciplinary design team as a team member	ILO4: Able to lead and function professionally in a team environment.
10	Rate your confidence to provide leadership in a multi-functional design team	
11	Rate your awareness of professional ethics and social responsibilities of a design engineer	
12	Rate your confidence and skills in oral communication (technical presentations)	ILO5: Use different modes of communications effectively to present outcomes of design activities.
13	Rate your confidence and skills in written communication (hand sketching, engineering drawings and technical reports)	

The pre-survey questionnaire was administered during the first lecture session of the subject. Students were clearly informed that the information is collected anonymously and the ratings and answers given for questions has no effect on grading of the subject. They were asked to make an honest self-reflection to make the most appropriate rating for their current knowledge, skills and awareness. Total of 80 students completed the pre-survey questionnaire and there were 78 valid returns.

The same questionnaire was administered to 3rd year undergraduate students who have taken the same subject before it was remodelled. At the beginning they were explained the purpose of the survey. Altogether there were 40 valid returns. The objective of this exercise is to assess the effectiveness of the remodelled subject delivery and assessment by comparing the reported learning outcome achievements of 2 groups of students (Group 1: those who have taken the remodelled subject and Group 2: those who have taken the subject before remodelling).

Post survey questionnaires were administered just after the students finished the last assessment for the subject. The same questionnaire was used and the same set of instructions were given. There were 83 valid returns.

Lastly a focused group discussion was carried out with the participation of selected students to get first-hand information about the learning achievements using semi-structured format. There were 2 rounds of discussions with 9 local students (those who have completed their secondary school studies in Hong Kong) and 8 non-local students (those who have completed their secondary school studies overseas). The students were selected based on their final grades for the subject. Each group consists of students who got very good to poor grades and hence can be considered as a fair representation of the whole group. The focus group discussion lasted for 2 hours and facilitated by a design engineer from the industry with experience in conducting focus group research.

Results and Discussion

The results of the pre-survey conducted before the delivery of the remodelled subject is given in **Fig 1**. The survey results indicate that students have already had some prior experience in engineering design practice and have developed related skills to some extent. They have a relatively low confidence in their technical skills as indicated by the ratings given for ILO1 and ILO2. Closer to 50% of the respondents rated those two ILOs poor or very poor. They have a relatively high confidence in their soft skills as indicated by the ratings given for ILO3, ILO4 and ILO5.

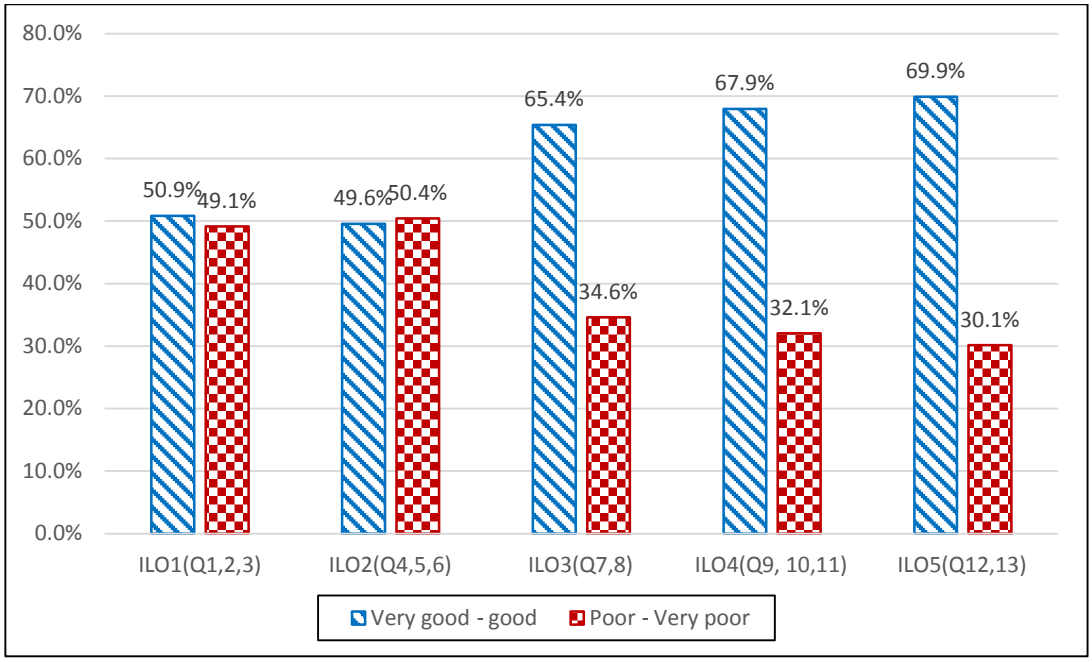

Fig 1 Pre-survey results for remodelled subject

The results of the survey done with senior students who have taken the same subject before it was remodelled is given in **Fig 2**. Compared with the results in **Fig 1**, it clearly shows positive improvements in students learning outcome achievements made by the subject offered using traditional approach. However, still closer to 20% of the student population rated their learning outcome achievements are poor or very poor in all areas. It is very significant for ILO2 (~30%) which is related to technical skill development.

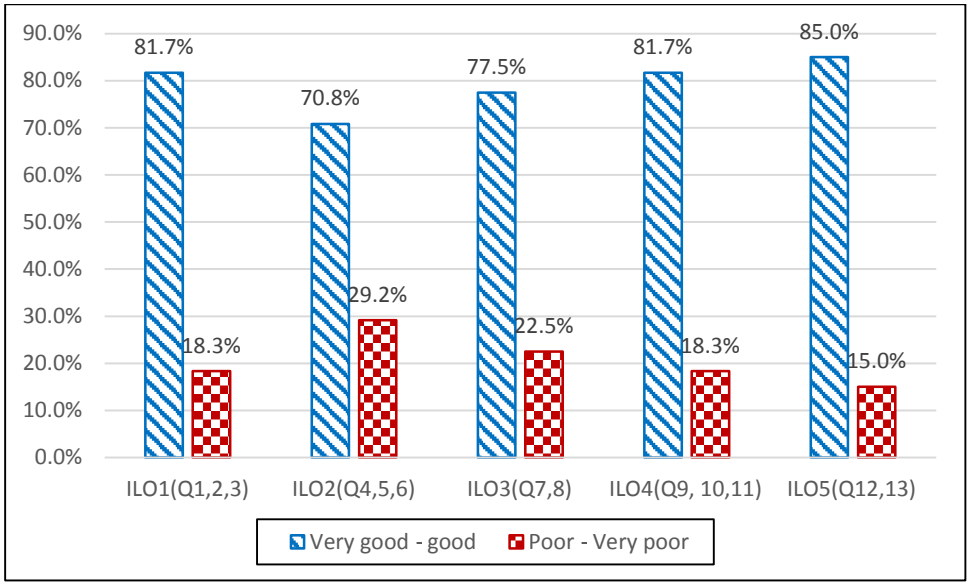

Fig 2 Survey results for the subject before remodelling

Fig 3 shows the post-survey results for the remodelled subject which is generated from the data collected at the end of the semester. Compared with the survey results presented in **Fig 2**, it showed that students have made considerable improvements in achieving their learning outcomes. It is a clear evidence that the new approach of subject delivery and assessment methods are more effective in achieving intended learning outcomes and well accepted by the students as well. The lowest improvement reported was for 'ILO4: Able to lead and function professionally in a team environment'. It is understandable that all the students in a group will not be getting an equal opportunity to perform leadership roles in a group project and also it is a personal trait that some students find it difficult to master. It is one of the areas we would like to pay more attention in further improvements.

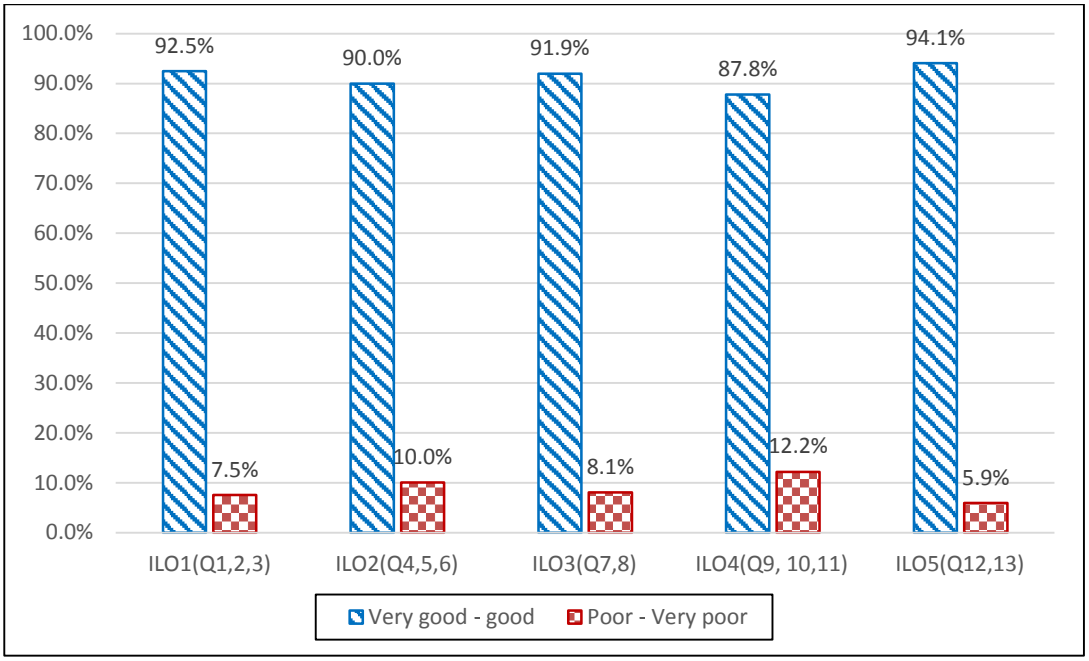

Fig 3 Post-survey results for remodelled subject

Table 2: Pre- and Post-survey comparison of learning outcome achievement

ILO	% Of students who rated "Very Good" or "Good"		
	Pre-survey	Post-survey	% improvement
ILO1	50.9%	92.5%	81.7%
ILO2	49.6%	90.0%	81.5%
ILO3	65.4%	91.9%	40.5%
ILO4	67.9%	87.8%	29.3%
ILO5	69.9%	94.1%	34.6%

Conclusion

An existing engineering design subject from HKPolyU Mechanical Engineering programme has been remodelled to provide the students with a better learning experience. The focus was to enhance the achievement of intended learning outcomes from the subject and thereby enhancing students' workplace related skills. The remodelled 'Engineering Design Fundamentals' subject was offered to 85 second year engineering students consist of both local and international students. The key changes made to the subjects are:

- Elimination of end-of-semester examination
- Introduction of in-class activities after each lesson to provide the opportunity for students to apply what they have learned immediately to solve mostly open-ended problems in groups or individually
- Introduction of rubric-based assessments
- Introduction of guest lectures from expert design engineers from the industry and getting their service for assessments
- Self-paced learning with the increased use of facilities available in Learning Management System (LMS)

The effectiveness of learning outcome achievement was measured through pre- and post-survey questionnaires where students rate their level of personal learning outcome achievement. The data shows a significant improvement in learning outcome achievements. The most significant improvements were reported for ILO1 and ILO2 which are related to technical skill/knowledge development. These results were then compared with the results obtained from the survey done with senior students who have taken the same subject before it was remodelled. The results show a significant improvement in students learning outcome achievements which is a good indicator of the effectiveness of the remodelled subject.

The major limitation of this study is that the impact of teacher effect on the student's learning enhancement did not form a part of the result analysis. The assessment of learning achievements is mainly based on individual student's self-assessment. Considering the fact that ultimately, it is the learner who is in the best position to judge his/her own learning achievement, the outcomes of this study provide a more realistic assessment of effectiveness of the remodelled subject.

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Appendix: pre- and post-survey questionnaire

1. How would you rate your level of confidence in being able to design a system, component or process to meet identified need?	Very confident	Fairly confident	Poor confidence	Very poor confidence
2. Rate your understanding of the process, tools and techniques that the professional design engineers use to develop new products or systems.	Very good	Good	Poor	Very Poor
3. Rate your understanding of different factors need to be considered in a successful engineering design project	Very good	Good	Poor	Very Poor
4. Rate your current awareness of latest trends, developments in engineering product/system design and development.	Very good	Good	Poor	Very Poor
5. Are you aware of techniques, skills, and modern engineering tools including computational tools necessary for engineering design pracice?	Well aware	Moderately aware	Somewhat aware	Slightly aware
6. Rate your skills in using the techniques, modern engineering tools, including computational tools necessary for engineering practice.	Very good	Good	Poor	Very Poor
7. How would you rate your understading of and exporsure to various sources of technical information such as	Very good	Good	Poor	Very Poor

textbooks, scientific and technical journals, the library system as a whole, the internet, etc.				
8. Rate your current ability/skill of searching appropriate information for learning independently using variety of educational media	Very good	Good	Poor	Very Poor
9. Rate your ability to function professionally in a multidisciplinary design team as a team member	Very good	Good	Poor	Very Poor
10. Rate your confidence to provide leadership in a multi-functional design team	Very confident	Fairly confident	Poor confidence	Very poor confidence
11. Rate your awareness of professional ethics and social responsibilities of a design engineer	Well aware	Moderately aware	Somewhat aware	Slightly aware
12. Rate your confidence and skills in oral communication (technical presentations)	Very confident	Fairly confident	Poor confidence	Very poor confidence
13. Rate your confidence and skills in written communication (hand sketching, engineering drawings and technical reports)	Very confident	Fairly confident	Poor confidence	Very poor confidence