ABSTRACT

Hands-on practice is an excellent learning medium for students, and we have developed a competition-based module to teach essential hard technical and soft project skills to students in mid-curriculum. Four groups of students were selected to participate in a 150 hour pilot module. The groups were tasked to design and build a wall-climbing robot with hammering ability to identify poorly adhered tiles on vertical walls. Training on the working concepts and the practical aspects of robotic design, electronics, sensor technology and electro-mechanical design was provided. The students integrated these knowledge components to produce a climbing robot as a major embodiment of the learned technique. On completion of the project, students competed for top robot honors by demonstrating their robots’ movements and faulty wall tile identification capability to a panel of judges. In this paper, the different teaching stages in the module; the learning assessment methods and results, as well as the student comments collected throughout the competition-based module are detailed.

KEYWORDS
competition, climbing robot, learning, assessment

1. Introduction

Based on the recent studies [1], industries required engineers to have strong communication and teamwork skills, knowledge in social, environmental and economic issues, and good understanding of fundamental engineering practice. However, traditional engineering curricula are too focused on the topics and content of the technical courses, teaching methods, and assessment criteria for students to
show understanding about the taught subjects. These curricula do not provide adequate opportunities to students to exercise their practical design techniques, teamwork experience, communication skills, as well as social, environmental and economic issues. Also, the concept to sufficiently relate the theories to practical engineering systems is missing. Nowadays, universities are modifying programs and course structures to facilitate their students to acquire practical knowledge and skills which are needed by the industries. Many institutions change their teaching approach in some courses from curriculum oriented to outcome based learning and project based learning models [2,3]. The students completing these courses are required to demonstrate that they achieve a set of specified learning outcomes.

Hong Kong University of Science and Technology (HKUST) has been designing outcome-oriented curriculums which explicitly set out the objectives for engineering students to accomplish upon their graduation. In January 2009, a competition based course on climbing robot was designed and implemented for a group of second year students from Mechanical Engineering Department. The course provided opportunities for students to fully participate in project based learning, to discover new technologies and be innovative. The competition at the end of the course gave students the practical experience to work in a multidisciplinary project, which was similar to what they would encounter in their future engineering career, and to compete with their classmates for the prizes.[4] With the advice from training instructors, the students were fully responsible for their design, choice of materials, and ways to meet the rules of the competition. The course was organized to enable the key learning objectives for the project can be met, i.e. team works, practical engineering knowledge, communication and leadership skills.

2. Specific Student Learning Outcomes

The main challenge for organizing this competition based course was to achieve the specific student learning outcomes which would be essential for their career upon graduation. The course provided an environment for students to work in teams to complete this engineering task through the cycle of project development. The learning outcomes were categorized into project management and technical ability. Students were expected to pick up the following knowledge and skills upon completion of the course.

2.1 Outcomes in technical ability

One of the major outcomes for the course was to develop students’ ability to apply their general engineering knowledge to design and build a workable climbing robot. The project gave students’ opportunity to understand the working principles and applications of the key components in a robotic system and the functions of the components, including motors, actuators, sensors and embedded computer system. Students exercised their gained knowledge to solve problems during the design and
testing stage, and it was proved to be more effective than formal lecturing and examinations.

Students participated in this course were expected to use multidisciplinary skills to build the robot, which included electrical, mechanical, electronics and computation aspects. Each individual member in the team has a certain role to play and their responsibilities depended on the in-depth knowledge about various parts of the robot. Apart from mechanical engineering, they have the opportunities of working in other disciplines of engineering which are essential for the completion of the task. They developed abilities in the use of engineering tools related to the specific disciplines, i.e. oscilloscopes, signal generators, development tools for embedded system, lathe/milling machines and CAD/CAM software design tools. The laboratory and workshop provided the environment for the real industrial project so that students could gain understanding about the requirements for professional practice which they would face after leaving the university.

The competition based learning approach facilitates the students to take a system approach to design and build a climbing robot. They have to complete the task following the life cycle of the project development. It consists of analysis of the specification, budget preparation, scheduling, robot design according to specification, test and commissioning. Students were given options in their design to cope with the rules in the competition and data needed to be collected from various alternatives. They have to design and conduct experiments, gather data and formulate the result for their decision process. The prototype robot which they built was a form of experimentation and the performance of the prototype was analyzed to provide feedback to their future designs.

### 2.2 Outcomes in project management

Students participating in this program could enhance their exposure in communication skills when preparing reports/log books and presentations. They have to communicate with their team members to reach a compromise for engineering solutions in various stage of the project. Discussion with their instructors facilitated them to learn how to express the problems and needs clearly for obtaining assistance. This is essential for students to develop their professional practice for their future career. Students were required to practise their teamwork skill. They learn how to maximize the strength and aware the weakness of their team members to accomplish the project objectives. They would develop their skills to work through the project life cycle and acquire the following abilities on completion of the course.

- Develop a master project schedule with tasks and deliverable milestones for production of an engineering prototype (e.g. planning, scheduling, tasks assignment and progress monitoring).
- Organize and prepare resources such as time, space, tools, components, and manpower, to meet the needs of the tasks.
Meet milestones and deliver the product on time within the given constraint in resources.

Throughout the project, the students would not have all the taught information for them to solve the technical problems. They would need to do literature research from books, magazines and internet on specific topics about the climbing robots. The information included how other research groups around the world solved the same sort of problem in wall tile inspection and their methodologies. This would enhance their development in lifelong learning skills. During the competition, students have to complete their tasks within the given time constraint and performed competition with their built robot in front of large audience of students and faculties. The training would give them the feeling of working under pressure which would happen in any of the engineering career.

3. Teaching and Learning Approach

To facilitate the unstructured learning of robotic technology in this competition based training, a design and fabrication was formulated for students to build a climbing robot in an open design and prototyping laboratory. The robot was equipped with hammering function to inspect the adhering condition of tiles on vertical walls. Students were given the opportunity to develop their own team structure and learn in an unstructured fashion to meet the desired milestone. They also conducted presentations and demonstrated their working prototypes in a competition environment. The students were guided to learn the practical skills to achieve their goals. The course included theoretical and practical contents for students to gain experience to build a prototype climbing robot.

At the beginning of the course, students were presented with the general principles, techniques and related technologies about robotics. A demonstration on the operation of an existing climbing robot was performed and students were given the opportunity to control the robot in checking the condition of the tiles. The aim was to enable students to have a good knowledge about the machine which they were going to design and fabricate. Students learnt the product development process by working in groups of four and through hands on experience to design/build various parts of the robot under the constraint in resources. Figure 1 shows the students’ design of the robot.

In the practical approach, students could access machinery such as lathe, milling and drilling machines to fabricate the parts under the guidance of workshop instructors. During the commissioning and testing stages, students were required to use their skills to identify, analyze and rectify engineering problems. The final competition gave incentive to students to produce the best design and workmanship, as well as achieving the optimum performance of the robot from their team work. During the competition, students were required to run their robot on a vertical wall and perform inspections on a number of selected tiles. The ranking of teams would depend on the time to complete the tasks, as well as accuracy of the inspections. Details of the schedule of the training module were given below.
The subject was delivered in the form of project through which students could acquire an understanding about the basic structure of a climbing robot and the manufacturing processes of key components. The project facilitated students to build a robot which could attach onto a vertical wall and move freely in different directions. A vacuum system needed to be designed to provide the suction force of the robot. The movement of the robot was achieved by means of motors through suitable gear boxes. A sensor for detecting the condition of the wall tiles would form an integrated part of the robot. A microprocessor based controller was developed in this project to provide all the controlling tasks for both movement and detection.

In order to cope with the tight schedule, with the entire learning process and project work completed within 20 days, some of the parts/components such as gear box, motor, and vacuum pumps were provided. Students would need to concentrate on the design of the robot in order to incorporate these parts and make them into a workable system. This required their skills in both software and hardware.

The schedule of the program was divided into five stages. Stage 1 was the introduction session during which the working principle of the major components will be presented. Students were briefed about their task and guidelines were given for them to work in groups to accomplish the goal of the project. A demonstration of various kinds of climbing robots was performed to let the student to aware of the engineering challenges which they were going to encounter. Computer aided design course was also given in this stage. Stage 2 was the detail design of robot system and student used computer aided design to help with their task. At the end of this stage, students gained feedback on their own design and made necessary modification and improvements, if necessary.
Stage 3 was the manufacturing period for the parts and body designed by the students, who spent most of their time in the workshops and laboratory. Stage 4 was the assembly of various parts provided and those designed/manufactured by the students. They should come up an assembled and workable climbing robot for the commissioning test at the end of this stage. Figure 2 shows the final product manufactured by the students.

Figure 2. The climbing robot designed and manufactured by students

Stage 5 was for final testing, presentation, and competition among the student groups. Figures 3 shows the track for the competition and figure 4 shows students participating in the competition.

Figure 3. Track for students’ competition
4. Assessment of the program

The review of individual components of the training commenced during the design of the course. Based on their industrial experience, the instructors formulated the course content to match with the learning outcomes. The various planned activities for building the climbing robot aimed to teach students the engineering knowledge and skills needed by practicing engineers. The objective of the assessment of the program is to improve the strategies in each of the activities for future implementation in similar training modules. It helps to find out the effectiveness of the program in addressing the outcomes. During the conduction of the course, discussions were held between instructors to review their observations on the students’ performance. The observation included students’ realization on the technical problems, teamwork between their members, their progress on design and fabrication, and their practical skills in making the parts [5]. The data provided information for the instructors to adjust the degree of their guidance and assistance to the students to accomplish their goals.

At the end of the course, students were required to complete a questionnaire about their views to the program. The questionnaire addressed their comments to the contents, program structure, teaching/technical staff, facility and the schedule. Analysis of their feedback data revealed that majority of the students (93.3%) found the program was useful and enjoyable. They found that the “whole training program covered different aspects of modern manufacturing process such as project planning and design fabrication. They expressed that the program prepared them for final year project and they could be familiar with the machinery in the mechanical workshop. Students considered the training program was interesting and making a climbing robot was a great challenge and fun. They emphasized the practicality of the training program which provided them with practical experience on design and manufacturing. The techniques included programming, building electronic circuits, design/build mechanical parts and
assembling them into a prototype machine. They viewed the process of problem solving and designing was valuable to them and the program could help to consolidate their knowledge or concept which they learnt before. In addition, students found that the staff was supportive, helpful and nice.

However, quite a number of students suggested allowing more autonomy on their robot design, i.e. they could choose some major parts to suit their innovative ideas. This indicated that students were capable of completing the task in the predetermined period and they were looking for additional challenges in their project work. Modification would be made on the future courses to facilitate them to further exercise their practical skill. The changes would include the design of automatic control system for the vacuum pump, as well as selection of suitable rating of motor, gearbox and wheels. Students have also indicated the limitation on the number of lathe/milling machines available for them to carry their parts fabrication tasks. They have to wait in turn for using these machines and some time was wasted in the queuing. Staffs were reviewing the space constraint with senior management of the university to see if additional workshop spaces with machines can be assigned for these training courses. A better time slot booking arrangement would be implemented in the future courses to help students to share the existing facilities more efficiently.

5. Conclusion

The paper described the development of a competition based course with specific outcomes to a group of students. It looked at how a tailor made course was developed to match with the objectives in the practical training for the students. The content of which was quite different from the traditional classroom based lectures. The structure of the course was planned to ensure that the outcomes were met, other than concentrating on the delivery of specific course topics to the students. The outcomes were formulated based on the industry’s requirements for engineering graduates. Despite the fact that the students are of mechanical engineering discipline, they were given a microcontroller platform for their hardware and software development. Through this training, students could understand the operation of an embedded module in an electromechanical system which is common in the industries.

The competition provided challenges to students and gave them opportunities for their creativity in the design and techniques to satisfy the rules of the competition. It helped the students to develop their initiatives which they have not practised in their routine lectures. One of the benefits about the competition was that participants faced engineering problems in different disciplines in order to run their climbing robot in the contest, i.e. computer, electrical, electronics and mechanical engineering. With the assistance from the instructors, students were trained to complete their projects under the constraints in time, budget and facility. The result of this practical course indicated that the participated students were able to apply their knowledge in the design and fabrication activities. They felt that they learned many of the theoretical engineering phenomena through their practical works and achieved the outcomes as set
prior to the commencement of the course. They could extend their knowledge and experience across the
different disciplines of engineering, as well as developing teamwork and management skills for their
future career as an engineer.

To further enhance the content of the course and achieve better outcomes for the students, future
works would include identifying latest technologies in robotic engineering and integrating them in the
form of tasks in the projects. The progress of the students should be closely monitored so that the
complexity of the tasks in design and fabrication could be adjusted to match with their ability. The
finding should also form the guidelines for similar courses. Another improvement would be in the area of
assessment for realizing if the students have achieved the program outcomes after going through the
process. In additional to questionnaires, methodologies such as interviews, quiz and continuous
assessment, can also be developed to extract the feedbacks from students and evaluate the effectiveness
of the course.

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