ENGINEERING AND DESIGN: AN INTEGRATED COURSE WITH REAL WORLD PROJECTS

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ABSTRACT

This paper presents a project-based course which demonstrates engineering design process by integrating various fields and skill sets in order to give students a realistic experience of what engineers do. This course, namely engineering and design, is delivered to a mix of students from electrical and mechanical engineering background. It is the final component of a set of three project-based courses offered as an engineering enhancement program. The primary objective of the course is to expose students to design principles and application of engineering methods in solving real world problems. Students from two different disciplines work in teams to develop solutions. The course consist of conceive, design, implement and operate (CDIO) elements primarily. Nevertheless, as an integrated course it aims to link diverse fields of engineering as well as develop social, communication, and teamwork skills of our students. This paper will present the thought process behind the development of this project-based course and its implementation together with our preliminary evaluations and observations.

KEYWORDS

Integrated curriculum design, project-based learning, active and experiential learning. Standards: 3, 5, 7, 8

INTRODUCTION

An important aspect of CDIO framework is the integration of topics such as communication, entrepreneurship and leadership skills in engineering education. Effective communication, participating in team work, leadership and managerial skills are among the most discussed areas in education literature (See for instance, McCowan (2002-a), McCowan (2002-b), Tenopir (2010)). Zaharim et al (2009) show that communication skills, problem solving and interpersonal skills are the three most agreed and necessary soft skills in addition to technical skills in the Asian context. It is important to note that communication skill is not limited to fluent presentations. Modern engineers need to be able to communicate their ideas in various forms ranging from writing reports to intricate technical drawings, effective poster designs to fluent presentations.

Another challenge for present engineering graduates is to be familiar with various disciplines and understand that engineering solutions may require an integration of various diverse disciplines such as biology, chemistry, design, and so on. This is evident with the advances made in technology, nowadays boundaries of distinct branches of engineering is getting blurred. Therefore, in our curriculum, we try to build awareness that engineering problem solving involves an integration of various disciplines. In Singapore context, where there is limited manpower and resources, our graduates need to have multiple skills and be industrious to succeed in a competitive industrial environment. This implies that engineering students should be versatile and avoid developing a single track expertise. We concluded that integration will play a vital role in our graduates' professional life based on the industry feedback we have gathered over the years. In order to address similar concerns, there are many initiatives reported in literature. For instance, Dederichs et al (2011) inculcate Trans-professionalism in building design so that graduates can easily work in a multidisciplinary team. Linder et al. (2001) present integrating engineering science and design. Froyd et al. (2005) debate the importance of integrating various disciplines in the engineering curriculum extensively. In our institution, we have implemented several strategies to integrate such skills to prepare our students to real world challenges. A primary domain to implement these initiatives was through an engineering enhancement program which students take in addition to their regular course.

The current environment for engineering graduates is competitive and industry demands highly skilled engineers. On the other hand, there is a steady decline to pursue a career in engineering among the students. Based on our interaction with students over the years, we observe that the perception of engineering being demanding and dull and students' lack of confidence in building or making things rank the highest among the many causes given. Considering these trends and the expectation of industry from engineering graduates, it was necessary to rethink engineering education. Therefore, in our institution, we strive to enhance not only the technical skills of our students but also other soft skills in order to prepare them for the challenges ahead. Based on our observations, we have identified four key areas that our students need to be strengthened. They are autonomy, integration, hands-on skills, and teamwork and communication skills. An autonomy supporting curriculum provides plenty of opportunity for students to make decision and determine their learning. This, in turn, encourages better engagement, personal satisfaction and intrinsic motivation (Iyengar (1999)). As mentioned earlier, integration is one of the key elements in our curricular change with the intention that our graduates will have a better understanding of engineering and how it is interlinked with various other disciplines. As a polytechnic, our institution collaborates with industry and responds to their needs while preparing our students for professional practice. The industry demands engineers with hands on skills who can fit into work force rapidly. Hence, by involving our students into project work and let them be familiar with various prototyping tools at the earlier stage of their study, we try to give them an understanding of what engineers do and inculcate a culture of making. Developing their hands on skills will consequently increase their confidence in making and building engineering artifacts.

We have developed a series of project-based courses and offered as an enhancement program in order to address issues discussed above. These courses are namely “Nature inspired design”, “Engineering inventions” (refer to Ercan (2013), Ercan et al (2014)), and “Engineering and design”. They are delivered sequentially in the first two years of engineering education. The level of complexity and course objectives vary successively depending on the areas of students’ learning that we would like to strengthen. This paper will present the last of the above mentioned project-based courses “Engineering and design”. It is offered to electrical and mechanical engineering students at the polytechnic level. The primary objective of the course is to introduce students to design principles and application of engineering theory into solving real world problems. It helps students identify the relation between distinctive engineering topics and create an avenue to discover the relevance of the material they are learning in the real world of engineering.

Research in cognitive science and education suggests that traditional lecture, tutorial, lab based instruction form is ineffective to develop skills that we would like to embed in our students. Therefore, these project-based courses are conducted in a studio environment by a team of faculty from four different departments with a plenty of active and experiential learning tools. Students work in teams, where each team is made of students from two different disciplines, throughout the course. This approach demonstrates a realistic example of engineering practice earlier in their study so that in their final year they have much better world view and mature ideas for starting a capstone project.

In the following sections, we will present the course in detail and our integrative approach which provided many possibilities for experimentation, as well as practicing engineering design and application. As learning becomes more experiential students are able to comprehend, retain and apply the knowledge better. Our preliminary results and observations show that the course is well received by the students.

AN OVERVIEW OF THE COURSE

Students were briefed early in the course that they will need to design and build engineering artefacts by taking inspiration from real world issues. These students are in their second year of engineering study and they have already been through other project-based courses in their first year. As students have gained more experience and developed their engineering skills from previous semesters, it is considered appropriate to immerse them into solving more realistic engineering problems. The project theme of the course is flexible and changes regularly; the current project theme is ‘water’, as students can relate to real life scenarios in Singapore’s context. This project theme presents plenty of opportunity to illustrate integration of mechanical, electrical and chemical engineering as well as math and science. The course duration is fifteen weeks. At the beginning, a selection of engineering topics, that would be beneficial to conceive and design stage in project development, are introduced with plenty of hands on activities, demonstrations and applications. These activities are in line with CDIO standard 8, which encourages engaging students directly in thinking, analyzing, and problem solving. Elementary fluid dynamics, flow in close conduits, water proofing techniques, data acquisition, water chemistry, water purification, are some examples concepts that are introduced through active learning methods. During conceive and design phase, students are expected to brain storm ideas that exploit properties of water or address issues related to water (e.g. water quality, filtering, and sanitation). During the implement and operate phase of the project, they are expected to deliver a working prototype. Students are exposed to various forms of communication throughout the course such as oral presentations, poster presentations, writing a short report and use of multi-media tools for visual communication.

Content

Module description

As mentioned, Engineering and Design is a multi-disciplinary module with numerous activities conducted by lecturers from different disciplines. Apart from activities, students need to work on a project that tackles issues related to the module's theme. Figure 1, shows how the activities and project time is allocated for students.

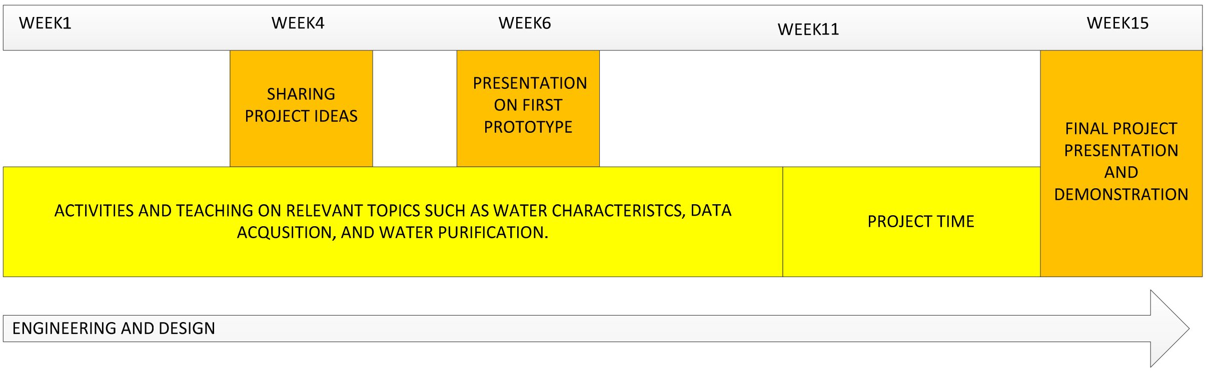

Figure 1. Schedule of Activities and Project Implementation

Activities and project work are assessed as part of the group assessments. Assignments, short quizzes and tests are used to evaluate individual's comprehension of concepts.

Activities

Electrical engineering activities explore data acquisition methods and hydroelectricity concepts. Students are given various sensors that sense different parameters of water quality. These sensors have different communication protocols hence each group deals with different control interface circuits, ports of a microcontroller, software packages and calibration techniques. The activity also promotes the importance of reading specifications from datasheets and using the information in their integration process. In the next activity, concepts of hydroelectricity are introduced and theories of generators, energy transformation and gears are reviewed and exhibited how they all work together. Each group submits a report of the theoretical explanations of the phenomenon they discovered in the activity which allows them to visualize the concept first before translating them into equations and understanding the parameters.

Mechanical Engineering activities helps students to understand the basics of water distribution systems and concepts such as buoyancy and drag that are inherent when designing systems for water bodies. Students get to make floating structures to appreciate how buoyancy and stability plays a role in designing ships and boats. They also get to realize how the shape of the structure affects the drag which contributes to the fluid dynamics of the surface vehicle.

Chemical engineering activities introduce students to water chemistry and physical and chemical properties of water such as pH, turbidity, total dissolve solids, total coliform and alkalinity. They learn methods to determine the concentration of pollutants in water using the simple characterization tools that they have made in the electrical engineering activity namely pH meter and turbidity-meter. After understanding the characteristic of water, students design and evaluate a method to treat contaminated water to produce clean and drinkable water using chemical and physical treatment. They experiment with different types of coagulants and its concentration in the coagulation process. While in the flocculation process, they study the impact of the stirring speed and duration on the settling time. On top of that they also investigate different type of filter materials (charcoal, sand and anthracite) and their configuration for the filtration process. Before each of the experiment was conducted, a proper design of experiment was performed and the results obtained were analyzed using hypothesis testing. Besides that, issues on water management, application of effective water resource management, factors that affect water scarcity are also discussed.

Students also require the knowledge of hypothesis testing for analyzing their data in the chemical engineering activity. However, they had not yet been exposed to this topic in their core engineering math courses. Hence, the teaching team applied the “Just-In-Time Teaching” strategy to teach students concepts of hypothesis testing so that they can quickly apply this math concept to solve a real application problem. Students were also taught how Microsoft Excel can be used to perform simple hypothesis testing analysis on data.

Project

Students choose and conceive their project topic, in line with course theme, through brainstorming sessions and are to present their design ideas with the aid of prototypes. As shown above in Figure 1, there is an exclusive dedicated period provided to project implementation and operation phase which is about four weeks. The project cycle starts from the first week and each group is given a milestone that they need to meet and a budget that they have to manage for their purchases. Students make their first presentation using their prototype, or scrap model, to a panel of experts on the sixth week. Panel is made of faculty members with engineering, design and communication expertise. A critique on the project and a feedback on technical challenges, oversights and issues are given in an open and direct manner. In the last week of the semester, each project group makes a formal presentation and demonstrates their project to the same panel.

Behavioral Competencies

Apart from creating an avenue for students who enjoy hands on projects and discovering scientific phenomenon through them, the module aims to bring positive shifts in behavioral characteristics of the students that will help them in their grooming process as mentioned earlier. The activities and project sharing sessions comprise short pitches of ideas to formal presentations. This helps students to be habitual of being prompt at sharing ideas and sharpen their communication skills. The project theme is set in a realistic context so that students are comfortable with uncertainty in the process of generating an idea for their team. Sharing sessions are assessed on attributes such as innovation in approaches taken and curiosity to learn new skills.

Example activities

Hydroelectricity

Hydroelectricity concepts are introduced in this activity through several experiments. The students start off with how the angle of a penstock in hydroelectric power stations affects generation by altering the angle of flow through measuring the flow rate. The next task would require students to use a waterwheel coupled to a DC motor as shown in Figure 2. The height and flow rate of the water source is measured and the voltage induced is captured. Students realize that as height increase, they are able to generate enough electricity to light up an LED. The activity further evolves to attach a gearbox with the motor's shaft. Gear ratio, speed and torque of the gears are analyzed to increase the voltage induced. This also helps recap activities dealing with gears which students have gone through in their previous project course (Ercan et al 2014).

Figure 2. Inducing voltage using waterwheels to understand the concept of hydroelectricity

Water Distribution System

This activity deals with the basics of a water distribution system. A brief historical background of ancient plumbing systems is given. The hands on activity starts by giving the students centrifugal aquarium pumps without any performance data and they need to characterize the performance (flowrate vs head) of those mystery pumps. The characterized pump curve is subsequently to be used by each student in solving a simple (single pipeline) hypothetical water transport problem on paper as homework. The experiment setup is shown in Figure 4. The activity also emphasizes on the analysis of flow rate and pressure losses in a serial pipe system, as students need to characterize the pumps given to them in order to obtain the result. Figure 5 shows students in this activity.

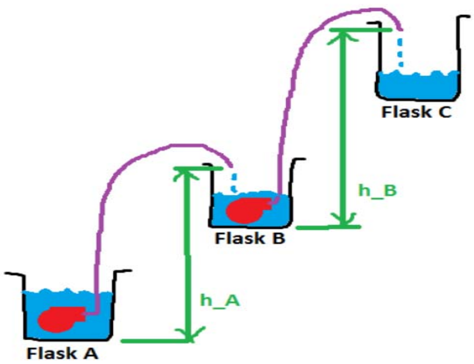

Figure 3. Pump characterization experiment setup

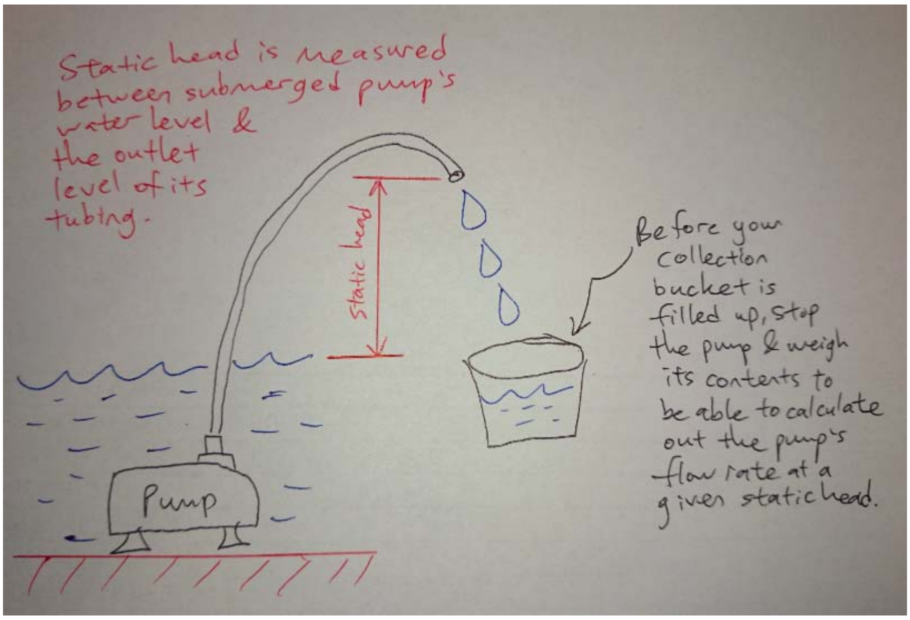

Figure 4. Pump characterization experiment setup diagram as written down for students.

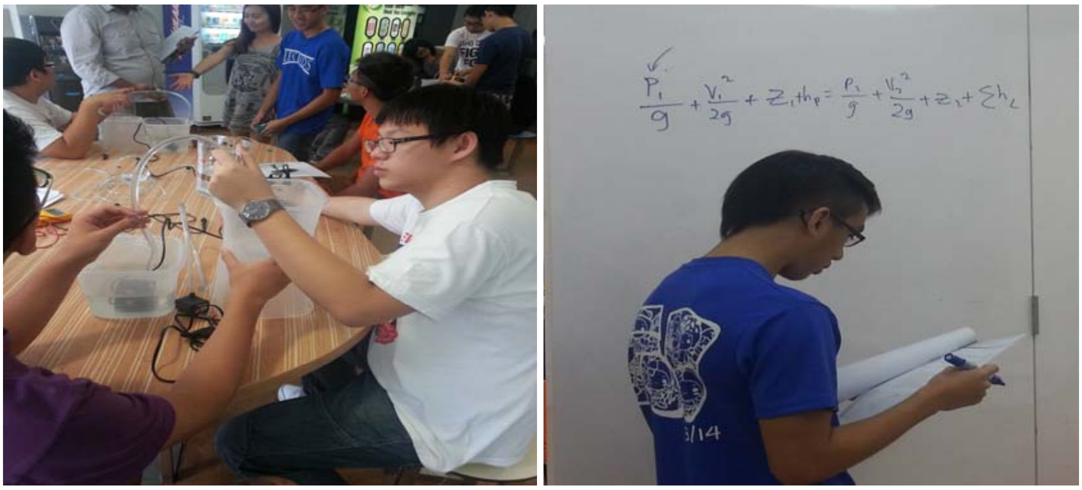

Figure 5. Students exploring the basics of water distribution systems

Buoyancy and stability of a surface vessel

For this activity, students are given a brief refresher lecture on the concept of buoyancy, and then introduced to the concept of stability for buoyant objects (e.g. Overturning and righting moments, metacentric height, etc.). Students construct a test vessel out of craft sticks, Styrofoam, and glue (see Figure 6). It is required that the test vessel will be able to carry the weight of two full soft drink cans in any orientation. Design freedom is encouraged and students can do a short research to know more about different possible hull configurations (e.g. mono vs multi-hull) that can be constructed. Each group uses a test vessel that they built to conduct an experiment to obtain overturning moments versus various tilt angles. They plot the result as a graph as shown in Figure 7. Furthermore, they need to calculate the vessel's metacentric height for only one axis of rotation.

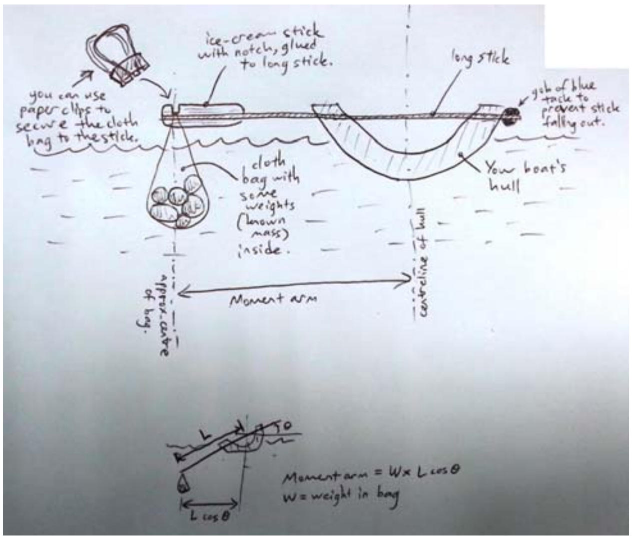

Figure 6: A simple sketch given to students to help them set up the buoyancy experiment.

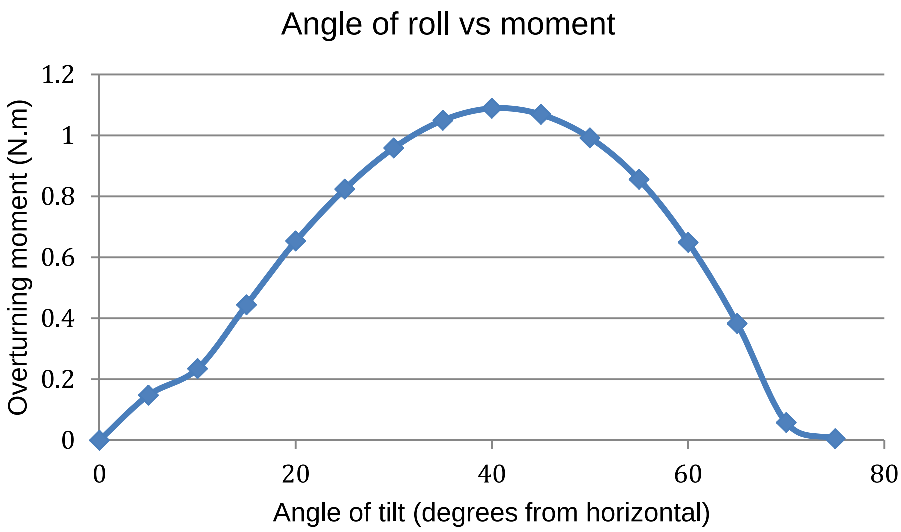

Figure 7: Graph of overturning moment vs angle of tilt as measured by a student group of their vessel.

Hypothesis testing activity

Students were introduced to the concept of hypothesis testing by first going through mini examples on normal distribution and sampling distributions. The examples required students to share within their group what they had learnt from the topics and how they could use Microsoft Excel to solve the questions. Work examples on hypothesis testing also required students to distinguish the difference between “paired-sample test” and “independent samples test”. The team hoped to establish a better understanding of the topic through this collaborative learning experience. Immediately after this activity, students embarked on a water filtration activity, which required them to apply what they have learned in the Hypothesis Testing activity to analyze their data.

Water filtration activity

In this activity, the students build the most effective rapid water filter possible by using the materials of their choosing such as fine and coarse sands, pebbles, charcoal, anthracite, kapok and other natural materials. To measure the effectiveness of their rapid water filter, they compare the turbidity, pH and conductivity of the water before and after the filtration process. Out of these 3 important water properties, they need to decide the most important one for their hypothesis testing and evaluate using t-test for comparing means of different population. On top of that they need to explain the functions of the respective filter material and how different configurations could give different results in producing clean water. Figure 8 shows snap shots from this activity.

Figure 8. (left) Measuring the pH and turbidity of dirty water, (right) measuring the pH and turbidity of filtered water

Project examples

During the implement and operate phase of the project, students are expected to deliver a working prototype. Since, students already have design and build experience earlier, the expectation on the quality on the project outcome is significantly higher. More than twelve different projects are produced in each semester. In the following, we will describe a few of them in order to give an idea about the type of project students are producing.

Oil Spill cleaning robot

A group of students built a robot that imitates the movement of a snake and is able to swim on the water surface. The buoyancy calculations were done to make the robot be positively buoyant. The control circuitry was placed in splash proof casing at the tip of the robot and servo motors was used to actuate the sway motion of the snake like body. The body was fragmented into smaller pieces and linked to each other to bring in the flexibility. The oil absorbing material was wrapped around these fragments and designed to be removed and replaced with new material with minimum effort. This project demonstrates students have used their knowledge from mechanical, electrical and chemical engineering areas. Figure 9(a) shows the robot in action in a swimming pool.

Amphibian vehicle

The amphibian vehicle was designed to be able to navigate on land and be able to go directly onto the surface of the water without any modifications in its structure. The vehicle was controlled using a RF controller. The electronics were cased in a self-made water proof compartment that had a waterproof cap to be removed for exposing the charging connector for the battery. The frontal wheels were waterwheels to ease the propagation in water as shown in Figure 9(b) below.

Water quality monitoring device

The water monitoring device is able to collect water quality parameters and analyze the data. An algorithm was put in place to crunch the data and send a wireless signal to alert a user of the anomaly of data collected. The device is sunk at the bottom of the water body and connected to a flotation device through a cable. Floating device includes a wireless communication antenna and also a solar panel that powers the electronics. The self-sustainable water monitoring system is shown in Figure 9(c).

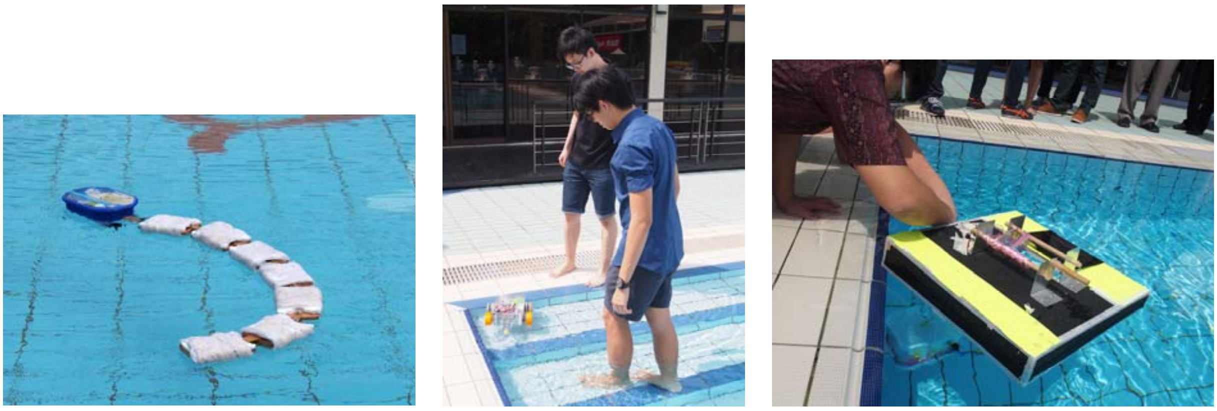

Figure 9. Some of the student projects in Engineering Design (a) Snake robot for filtering oil from ocean surface (b) amphibian vehicle (c) a sensor station collecting several sensor readings and transmitting to a computer wirelessly.

RESULTS AND DISCUSSIONS

The student experience is an important element to measure as it has immediate impact on achieving the course objectives. Most of the students who are taking the course have an aptitude for hands on activities and find project work stimulating and a challenge they wish to achieve. However, conducting a feedback session at the end of the course has few handicaps. It does not allow room for active changes, corrections, or improvements for the current group of students. It is normally a good measure for making improvements for the next time the module was offered. Furthermore, it is somewhat biased based on the particular student's level of achievement in the overall project.

Above considerations led us adopting a feedback system which integrates a motivation framework known as self-determination theory (Ryan and Deci (2000)). In this theory, motivation can be classified into four types; a-motivation, external regulation, identified regulation and intrinsic motivation. Determining the type of motivation most students are driven by in the classroom is helpful for educators to decide upon what aspect of the activity and student experience needs attention. Often, changes in activity style and assessments are made in a week's time for the very next session. This can help in achieving the experience that students enjoy and look forward to through a positive shift in the level of motivation.

The feedback is taken almost every session to be able to track changes in motivation levels and aid in determining the factors that may have led to a certain level of motivation. The questions are each framed to indicate a type of motivation and also the intensity. Figure 10 shows an example of "a-motivation" level result in the classroom for a particular activity. Students respond to the statement "I do these activities because I have no choice" and scale their feeling. Response shows that majority of the class were motivated.

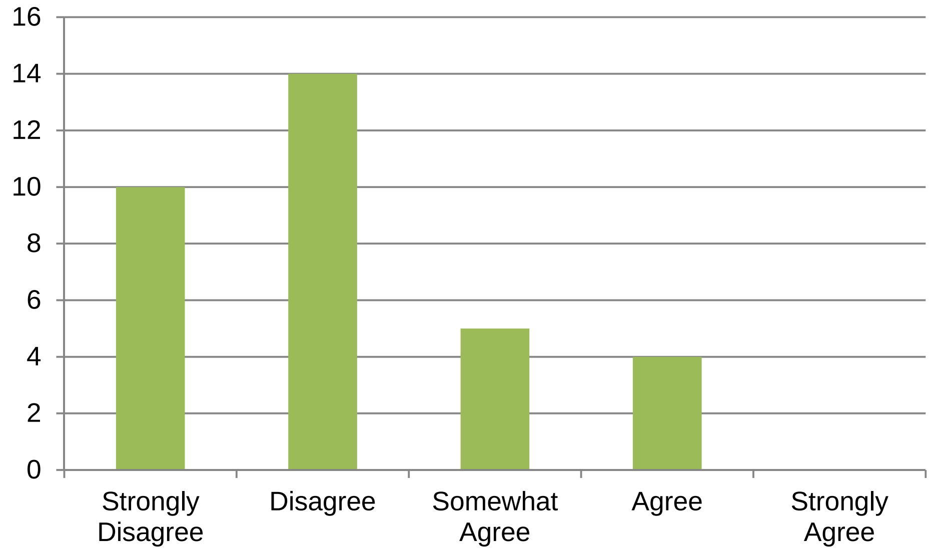

Figure 10 Response to the statement "I do these activities because I have no choice" regarding their engagement level in the activity

Whereas, to investigate whether intrinsic motivation is present in the classroom, statements such as "I do these activities because I feel good" were modelled. The response to this statement was also positive as shown in Figure 11.

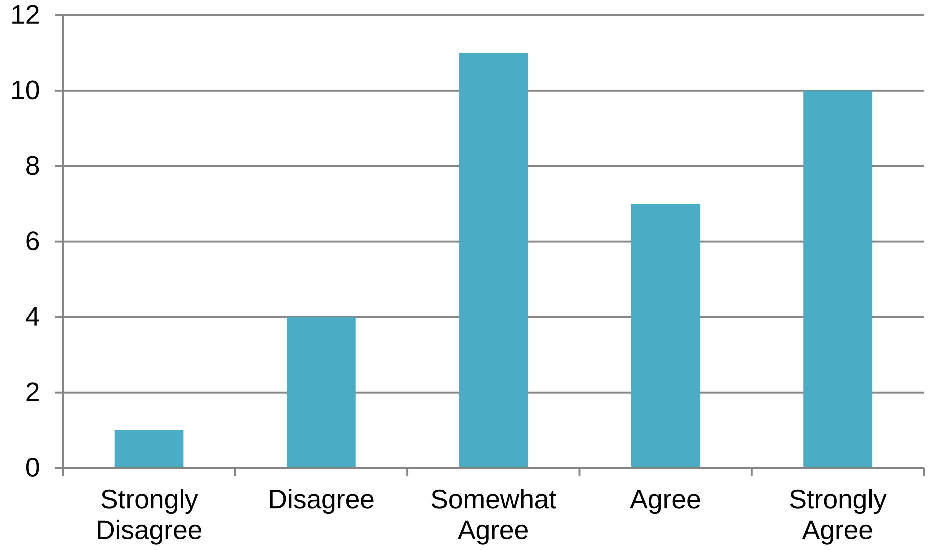

Figure 11 Students response to the statement ""I do these activities because I feel good" which indicates level of intrinsic motivation in the class room

The survey form has 16 such questions and each set of 4 questions represents a type of motivation. The motivation level was calculated using the Situational Motivational Scale (SIMS) as described in Guay et al (2000). The data shown here is for the activity "Water Distribution System" where students characterized a pump. The motivation level indicated that on the average students had motivation of "identified regulation" in nature. This indicates that students did not feel that they were forced to go through this activity nor did they just do it to attain the assessment grades. Although they did not do it out of intrinsic motivation, they knew that the knowledge and experience acquired was important and would be beneficial in designing future projects. Figure 12 shows the shifts in motivation levels and these helped lecturers to probe into when there is a drop in the motivation level. For instance, in the third week, students responded that there were too many activities for a 4 hour period. It made them lose focus. On the seventh week, we observed another case of extrinsic motivation. This was due to overloading caused by many assignments and lab tests given in other courses which made it very difficult for students to meet their team members and prepare for their project work.

This data was useful in designing or altering the next activity to bring a positive shift towards acquiring intrinsic motivation in the classroom. Activities can reflect relatedness to real world scenarios and give students a sense of feeling being competent and ensuring that they are in control of their learning. These attributes bring in the positive shift that we would like to see in the classroom.

An important part of the evaluation was a focus group interview with 10 students. After the focus group interview, students were requested to verify the inference and interpretations of the student experience made by the evaluator in order to reduce the influence of recording errors and guarantee more valid interpretations. The focus group concluded that our integration effort was a very positive feature of the course, both in terms of technical integration (e.g., within the engineering field and across the engineering disciplines involved) as well as with the other generic competencies (e.g., teamwork, communication). Students also reported a great sense achievement to meet the learning outcomes and project deliverables. However, the students also found that module content is intense and deadlines were tight. Furthermore, they had limited access to project lab in their free time. These issues basically demands better time management by students and faculty.

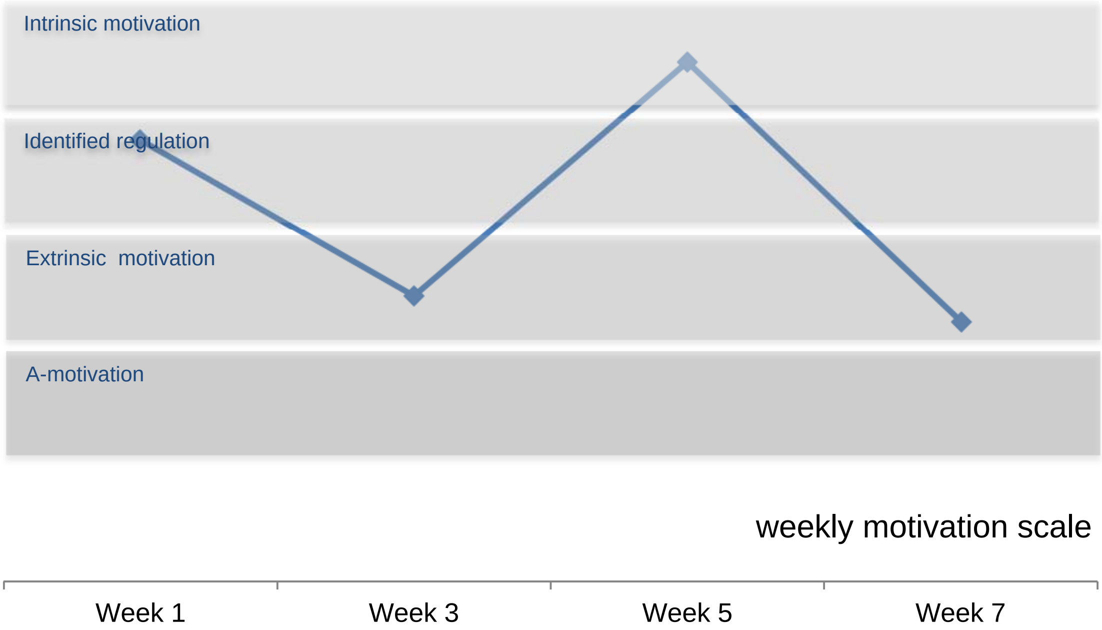

Figure 12 Survey results for measuring the level of motivation of students

CONCLUSIONS

This paper presented our initiative for designing an integrated project-based course. Based on our experience, we can conclude the following factors are important for the successful implementation:

Teaching team: Team should include lecturers who are comfortable with one another and have a strong passion in experimenting with new pedagogic approaches.

Topic: Choosing a relevant and realistic project theme is critical to gain students attention. Dealing with a familiar problem motivates students and heightens their sense of worth. Choosing a right theme also helps demonstrating integration of various technical areas.

Delivery: Well-structured material and activities prepare students into project work. These activities introduce some of the fundamental engineering concepts relevant to the project theme. It broadens student's awareness on real world problems and helps them establish the connections among various topics.

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BIOGRAPHICAL INFORMATION

Rubaina Khan received her Masters in Automation and Computer Control from Nanyang Technological University, Singapore in 2008 and currently a lecturer in School of Electrical and Electronic Engineering at Singapore Polytechnic, Singapore. Her research interests are in underwater robotics. She is also interested in experimental pedagogy techniques and in designing learning experiences that foster students' creative capacities and also encourage students' development as unique and self-directing learners.

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Noel Kristian received his Ph.D. degree in chemical engineering from Nanyang Technological University, Singapore, in 2010. Currently, he is a lecturer in chemical engineering at the School of Chemical and Life Sciences, Singapore Polytechnic. His research interests are in the development of low cost materials for fuel cells, super-capacitor and lithium ion batteries and development of integrated biofuels production using waste from agricultural home-based industry and he has published vastly in refereed conferences and journals in these fields. He has been actively involved in the efforts to transform engineering education through active and experiential learning pedagogy as part of the engineering curriculum.

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Tune Chien Jung studied Mechanical Engineering at Universiti Tenaga Nasional, Malaysia, for his B.ME(Hons) and continued studies with the National University of Singapore to obtain his M.Sc (ME) in 2005. He has worked in positions such as a CAE Application Engineer for Numac Systems Technologies Sdn. Bhd.; Senior R&D Engineer (Mechanical) for Hewlett-Packard Singapore Pte Ltd.; and now, a Lecturer with the School of Mechanical and Aeronautical Engineering at Singapore Polytechnic since 2010. His experience and interest are in the field of consumer product design and development.

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