Developing Problem Solving Skills through a Project-Based Course as Part of a Lifelong Learning for Engineering Students

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Abstract**—**The purpose of this paper is to investigate how engineering students' motivation and interests are maintained through a project-based course in their lifelong learning journeys. In recent years, different pedagogies of teaching including entrepreneurship, experiential and lifelong learnings as well as dream builder, etc., have been widely used for education purpose. University advocates hands-on practice, learning by experiencing and experimenting throughout different courses. Students are not limited to gain knowledge via traditional lectures, laboratory demonstration, tutorial and so on. The capabilities to identify both complex problems and its corresponding solutions in daily lives are one of the criteria/skill sets required for graduates to obtain their careers at professional organizations and companies. A project-based course, namely Mechatronic Design and Prototyping, was developed for students to design and build a physical prototype for solving existing problems in their daily lives, thereby encouraging them as an entrepreneur to explore further possibilities to commercialize their designed prototypes and launch it to the market. Feedbacks from students show that they are keen to propose their own ideas freely with guidance from instructor instead of using either suggested or assigned topics. Proposed ideas of the prototypes reflect that if students' interests are maintained, they acquire the knowledges and skills they need, including essential communication, logical thinking and more importantly problem solving for their lifelong learning journey.

Keywords**—**Problem solving, lifelong learning, entrepreneurship, mechanical engineering.

I. Introduction

LIFELONG learning education is extremely important for students to focus on their personal development throughout lives either in formal or informal manners. Multiple benefits, such as being confident, helping succeed at work, staying healthy, connected, and fulfilled, etc. can be gained through lifelong learning [1]. In fact, lifelong learning skill is one of the key criteria required by industries and organizations recently. Employers expect the workforce to have not only skills and knowledges in a particular discipline, but also critical thinking and essential communications skills. Engineering education has been transitioning from the traditional/static and instructor-centered approach to the interactive/dynamic and learner-centered experience [2].

In recent years, different types of innovative teaching, such as experiential learning [3]-[5], blended learning or flipped classroom [6], Massive Open Online Course (MOOC) [7] have been reported to be an effective learning process for students comparing with the traditional teaching based on typical lecture-tutorial-examination model. Blended learning is classified as one of the e-learning modes [6]. It is a form to deliver a stable and standard content via online videos creating the opportunity for more face-to-face activities, i.e. group discussion, case study sharing session, reflection and presentation, and in-class exercises, etc. For example, Design and Manufacturing is a mainstream required course which introduces the basics of manufacturing processes for Mechanical Engineering students. In majority of tertiary institutions, the existing course contents are delivered via lectures, with students having little opportunity for interaction. To achieve the course learning outcomes in general, an effective learning atmosphere for students includes relevant reading and writing tasks, discussion and problems solving. However, students are lack of opportunities to work experimentally via the blended learning mode.

MOOC is another innovative teaching models to deliver varieties of learning contents online. The main idea of the MOOC is designed for majorities of dispersed learners to taste different subjects before choosing the right major in the college. Learners are able to access the reading materials, lectures, videos of a particular interest/subject from anywhere at any time with no limit on attendance. The course materials are designed and selected by academicians with reputations in world-class universities. Since the MOOCs have been all about studying at own pace and accessing to the course for free, one of the major challenges is that learners are found to be not interesting in completing the course [7]. Similar to the idea of blended learning modes, the MOOCs are also lack of opportunities to learn by experiencing or experimenting, in particular of courses with practical demonstrations, design and build components.

Apart from the two innovative learning models mentioned above, one of the promising educational approaches that has become wide-spread is Experiential Learning (EL). The idea of EL is beneficial for students to learn through a complete process of learning by doing and experimenting. Moreover, it is a well-known process to demonstrate a hands-on experience which is able to combine both the scientific knowledges and theories. Breunig [8] stated that EL enables students to actively engage with relevant real-world materials to generate deeper

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connections between conceptual and practical knowledges. This paper is written as a short communication to examine the critical issues of lifelong learning via a process of an EL and its impact on engineering education. According to the ideas' proposition in relation to problem identification in daily-lives proposed by students, performances of the built prototypes, students' presentation, feedbacks and suggestions from a project-based course, namely Mechatronic Design and Prototyping (MECH3907), thereby enhancing their problem solving and hands-on skills practically as well as fostering the development of these skills for life-long learning.

II. Background of MECH3907

Students majoring in Mechanical Engineering at HKUST were required to complete two industrial training modules as one of compulsory graduation requirements. The first one is a four-week full-time training held in an Industrial Center at other institution, to mainly focus on different hands-on practice, including SolidWorks, Programmable Logic Controllers (PLCs), Manufacturing processes, such as drilling, milling, etc. The second is another four-week full-time in-house training held during weekdays. Students are asked to use the knowledges and theories they have learnt from the first training to build a robotic system with a given instruction guide. They are required to form a team of 3-4 members to complete an assigned task. In this case, they are asked to build a robot without requiring to consider dimensions, design elements, materials' selections, etc. Since 2015, the four-week in-house training has been converted from a regular training with pass/fail grades to a credit-bearing course with letter grades, namely Mechatronic Design and Prototyping. The course structure includes lectures to provide fundamental knowledges of typical topics of Mechatronics, such as actuators and motors, controllers, integrated circuits, electronic components, etc. and was held in every Spring term. It was a 13 weeks course designed for the 3rd year students to gain hands-on experiences on Mechatronic system after a completion of a course of Design and Manufacturing 1 in the 2nd year.

Similar to the former second training, students are required to form a group of 3-4 members to design and build one physical prototype. Two topics, including Robotic Hand-gripper and Spinning Top System were used in the first two times (years 2015 and 2016) for students to design and build their own prototypes. It should be noted that students' creativities and design capabilities are limited by the topics given. Existing designs and alterations can be found in the social media platform. After 2016, students were keen on proposing their own topics for making the mechatronic prototype. In fact, it was found that the students are demonstrated to work in groups effectively and efficiently on making their prototypes, as their proposed ideas are generated based on their interests and motivations.

A. Course Learning Outcomes

To broaden the scope of innovative engineering education and to incorporate EL initiatives into Mechanical Engineering curriculum, MECH3907 [9] was one of the courses delivered using EL approach. The idea is to broaden the professional interests and exposure of students by enhancing their practicum/team-based experience via designing and building a physical mechatronic system. On successful completion of MECH3907, students are expected to be able to meet the following learning outcomes [9]:

- identify and formulate problems in multi-disciplinary environment
- design and conduct testing;
- apply problem-solving skills in mechanical engineering;
- develop a specification of product to meet needs;
- understand the manufacturability and its impact of engineering system and components;
- use engineering tools, techniques, and skills in engineering practice;
- enhance communicate skills;
- work in multi-disciplinary teams and provide leadership;
- understand the need for life-long learning and continuing education

It should be noted that the above course learning outcomes are extracted from the course syllabus of MECH3907 in the Department of Mechanical and Aerospace Engineering at The Hong Kong University of Science and Technology. These outcomes are designed to align with the program objectives and program outcomes which satisfy the local accreditation purpose for mechanical engineering students.

B. Assessment Tools

Since the course has been delivered using experiential mode for students to gain hands-on experience by designing and building a physical mechatronic system, final written examination was excluded. Assessment tools included four components are shown as follows:

- Peer evaluations (10%): To provide feedbacks and suggestions on each other's work
- Log-sheets (10%): To summarize an update of the design and build progresses
- Group Report (20%): To report the entire process of building the mechatronic system
- Group Presentation and demonstration of the designed prototype (60%): To provide a detailed explanation of the working principle of the prototype physically.

The performance of the designed prototype is evaluated by a number of factors, such as creativity, functionality, stability, etc. Final presentation, report, and peer evaluation are also used as part of the assessment tools.

III. Findings and Discussion

The current study is written as a short communication to examine the critical issues of lifelong learning via a process of an EL and its impact on engineering education. Students' feedbacks and their poll results of the course outcomes via questionnaire collected by the department are one of the main sources of findings for current discussion purpose.

In Spring/2015, a 3-credit course of Mechatronic Design and Prototyping has been delivered as a trial run to replace a four-weeks in campus training. A topic entitled Robotic Hand-

Gripper was used as a project title for students to design and build to complete the course. Fig. 1 shows a suggested robotic hand gripper design made using acrylic. Students were asked to redesign their own gripper using different mechanisms, such as rack and pinion, claw, linkage, etc. Their designed gripper was required to hold a table tennis ball, and to move from one pole to another pole controlled by a microprocessor on a given rotation base support. Fig. 2 shows a given rotation base support with 3 poles different lengths located in different positions. The rotation base support was also connected with the power supply. Students were also required to edit the given assembly language depending on the height, orientation of the poles.

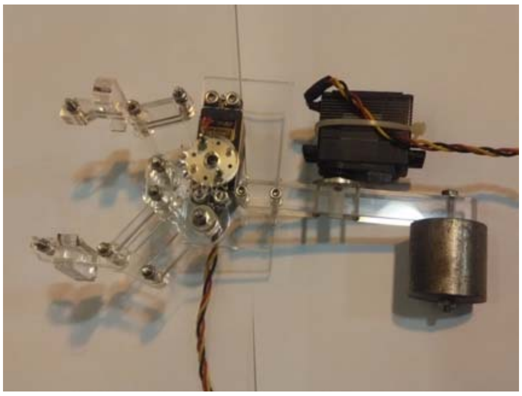


Fig. 1 A suggested robotic hand gripper design

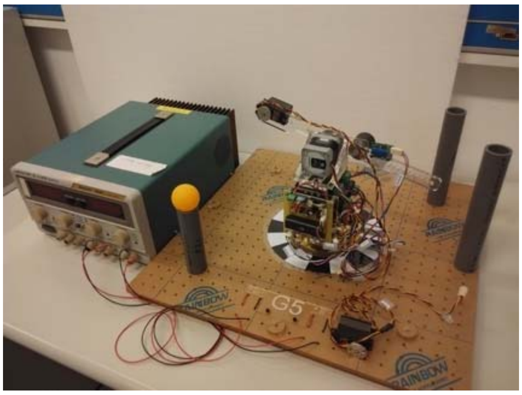
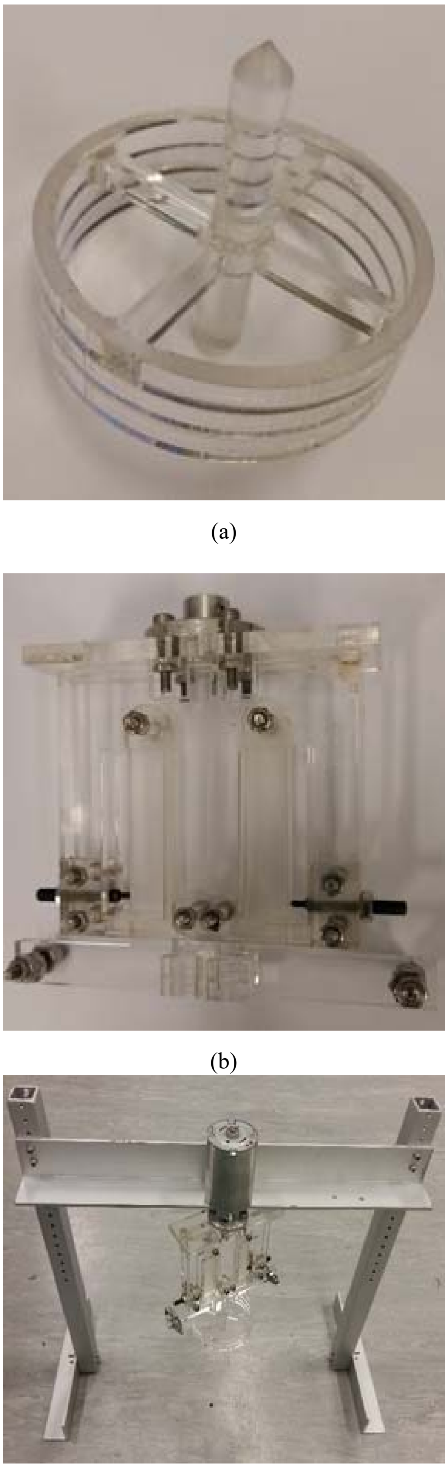


Fig. 2 A given rotation base support

Since the course was designed for students majoring in Mechanical Engineering, the most difficult part was coding and/or programming. In fact, courses related to programming/ coding were not provided in a typical mechanical engineering curriculum. Therefore, it was critical for students to demonstrate the problem-solving skills by modifying the given assembly language. A few comments from the student-feedback-questionnaire stated that:

> Regarding of electronics programming design - although basic programming framework for the gripping and moving motions were provided, we still need to rewrite the commands in order to fits our gripper design. Also, path design and gripping arm angle calculations were challenges at the programming stage.
>
> Students are able to learn programming and work as a team to complete tasks given.
>
> This course gives me a hands on experience to build a robot arm which is programmable and can perform specific task. We can learn a lot of practical skills throughout the course.



(a)

(b)

(c)

Fig. 3 (a) Reference spinning top design, (b) a holder and (c) a setup of the entire spinning top mechatronic system made using acrylic and aluminum

On the other hand, the course has offered the practical/hands-on experiences for building the mechatronic system, students were not only focused on working with the mechanical design of the gripper, but also on understanding the electronic components, such as servo and stepping motors, infrared and ultrasonic sensors, microprocessor, etc. It has provided opportunities for students to integrate all electronic components for completing the task.

After completing the first trial in 2015, the course was continuously delivered using a similar approach in Spring/ 2016. A topic entitled Spinning Top System was given for students to design and build their own mechatronic system. Fig. 3 shows a) a reference spinning top design, b) a holder and c) a setup of the entire spinning top mechatronic system made using acrylic and aluminum.

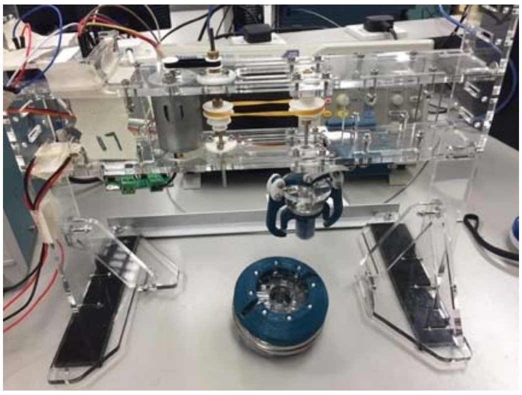
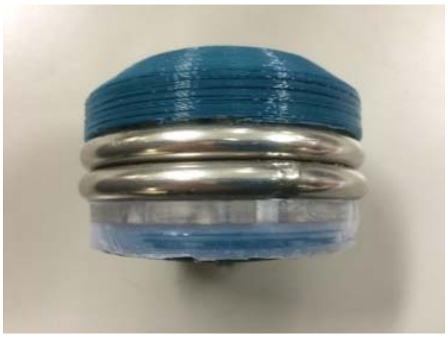
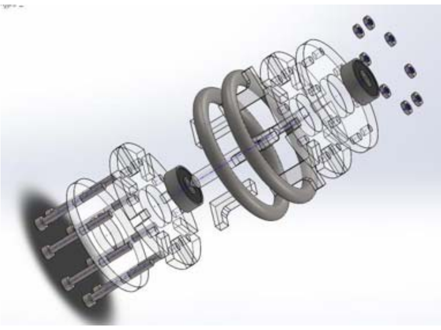


Fig. 4 One of the best spinning top systems designed and built by a group of 4 students



(a)



(b)

Fig. 5 (a) An enlarged view of the spinning top and (b) exploded view of spinning top using SolidWorks

Students were required to re-design a spinning top with holder using different releasing mechanisms. The dimensions of the spinning top and the setup (frame) were limited by 80 mm in diameter with a given shaft of 60 mm in length, and 350 x 200 x 300 (H) mm, respectively. It is important to note that comparatively less coding/programming is required in the spinning top system after collecting students' comments in the first trial. Fig. 4 shows one of the best spinning top systems designed and built by a group of 4 students. Fig. 5 shows: (a) an enlarged view of the spinning top and (b) exploded view of spinning top using SolidWorks. In Fig. 5, two steel rings were added to allow the spinning top to spin in a longer time. Also, two smooth casings were used to reduce the drag by covering the screws and nuts joined the middle acrylic and the steel rings.

Spinning time was one of criteria to assess the overall performance of the system, i.e., the heavier the top is, the longer time it spins. This group of students was demonstrated to identify the objective of the system and understand the way to achieve the better performance of the system. It should be noted that the concept of EL is important for students to gain hands-on experience by searching the materials, the knowledge, the principles, etc. they need. Also, they were able to demonstrate the cooperation and communication skills by building the system. A number of comments from students stated that:

> I like that this is a project-based course. The concept of experiential learning is very important and even if I did not learn everything about electrical components in mechatronic design, I learned more to work with a team and how to communicate with others.
>
> It provides self-learning experience and group cooperation opportunity.
>
> It encourages us to think about many innovative ideas and methods to realize them. It is a true engineering work instead of just a course.
>
> This course really gave us a hands-on experiment on how to design one product from scratch, which cannot be learnt in the classes that merely teach student theoretical knowledges. I like designing and this course really told me what an engineering be like.

Completing a number of attempts using both topics of robotic hand gripper and automatic spinning top system, it was found that students are keen on proposing a topic of mechatronic system they are interested in. Different comments were made by students and shown as follows:

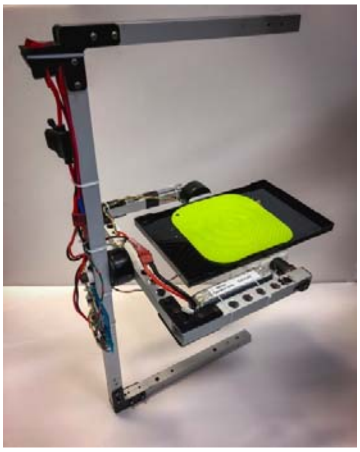
> Flexibility and freedom to do mechatronic system we want to for our project.
>
> Give us an opportunity to try working on something by ourselves
>
> It allows us to be creative. The course does not limit or narrow down our ideas in designing.
>
> It encouraged us to learn more about Arduino and control systems rather than just pure mechanical structure design and analyses.
>
> The multi-disciplinary nature really challenged us to study more.
>
> Providing a chance for us to create our own product.
>
> Stimulates and encourages students to think and apply

knowledge to design

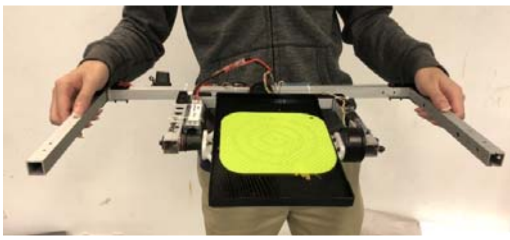
The course stimulates students to explore more on designing mechatronic machines in a practical context. Also, a free topic approach allows students to put their interests into studies, encouraging them to put more effort on the learning process. Instructor is kind and encouraging as always, he provides possible directions for students to brainstorm on when they face difficulties instead of giving direct answers.

We can choose our topic freely and try different ways to achieve goals.

Since 2018, students have been given an opportunity to design and build their own proposed topic. Figs. 6-8 show three different representative mechatronic systems designed by students. All ideas were 100% original and proposed by students. Fig. 6 shows a self-stabilizing food plate in (a) single hand mode and (b) two hand mode. The objective of the project in Fig. 6 was to design and build an intelligent food plate for the Parkinson's' patient. The prototype was demonstrated to deliver a meal from kitchen to table stably. Fig. 7 shows a sturdy and anthropomorphic mechanical hand. The objective was to design and build a low cost a robotics arm, in which fingers' movements could be simulated. In Fig. 8, it shows an Artificial Intelligent Reversi robot controlled by an Arduino Uno. It was a two-players connection game in which the human being could play against with the anthropomorphic robot. Based on the entire EL process, a number of features were demonstrated in the Reversi robot, such as AI coding for battling, black and white balls delivery mechanisms, sensors' system, etc.



(a)



(b)

Fig. 6 A self-stabilizing food plate in (a) single hand mode, and (b) two hand mode

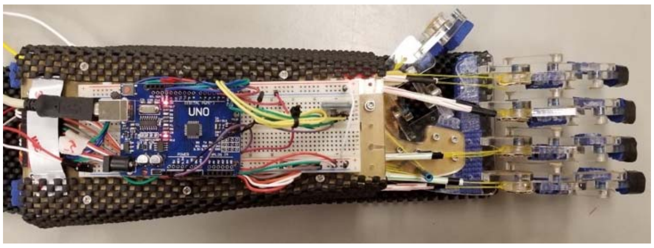


Fig. 7 A sturdy and anthropomorphic mechanical hand

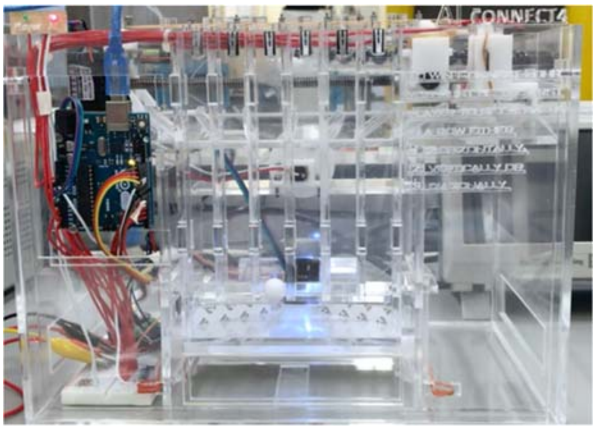


Fig. 8 An Artificial Intelligent Reversi robot controlled by an Arduino Uno

Students' comments made for either a fixed/assigned topic suggested by an instructor or a free topic proposed by students themselves, indicated that students enjoy challenges and freedom of proposing topics they are interested in designing and building. Students' comments have also pointed out that they acquire the knowledges and skills they need for solving the real-world problems, although they do not have a fundamental knowledge of operating particular component and system i.e. Arduino, control, etc., or a comprehensive instruction manual of building the prototype. Brookfield [10] stated that students receive the opportunity to acquire and apply knowledge, skills, and feelings in an immediate and relevant settings. Apparently, free topic proposition approach has demonstrated a positive impact on problem solving skills, learning process and on knowledge creation [4].

It is interesting to note that a student group (the one designed and built the Artificial Intelligent Reversi robot in Fig. 8) is inspired by the hands-on experience obtained from the course, to further extend the skills and knowledges in terms of robotics, control, design, and manufacturing for a real-world application. The students were motivated to develop their own robotic start-up business after graduating in 2019. Hummer Autosys Technology LTD. [11] has been established by two students from this group since August 2019. Fig. 9 shows an unmanned ground vehicle (UGV) designed by the students. The idea of UGV was to assist human for delivery, sanitization, garbage, etc. without unnecessary contact due to COVID-19. The UGV is able to demonstrate a number of features, such as navigation, delivery of goods, etc.

Fig. 9 An UGV designed by the students

The outcome of their achievement has demonstrated that students' idea can be transformed to real-world applications. Also, students are capable of developing their communication, interpersonal, technical, and last but not least problem-solving skills. In fact, the ability to solve a complex or an ill-structured work problem in the society and the world is the kind of skill demanded at a high-level performance [1].

IV. Conclusion

The course entitled Mechatronic Design and Prototyping has been delivered to students majoring in Mechanical Engineering via EL mode instead of the traditional lectures and tutorials. Numerous positive comments from students indicated that the use of EL mode for delivery of a standard course is an incredible learning experience. It is also a true engineering work with hands-on practice. Free topic proposition approach encouraged students to explore additionally on designing mechatronic system in a practical context. Furthermore, it has demonstrated a positive impact on identifying a practical engineering problem, thereby providing a corresponding solution even without a standard instructional manual/guide of building the prototype.

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