Integrating Introductory Courses for First Year Engineering Students: Systematic Strategy Using a Complex Problem

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***Abstract*— First year engineering students lack of understanding of the field and skills required as engineers make it hard for them to grasp the efforts needed on their development to become future engineers. In the Chemical Engineering Programme in Universiti Teknologi Malaysia (UTM), the Introduction to Engineering course was specifically designed to bridge the gap in students' learning and professional skills as well as understanding of engineering from their pre-university levels to prepare them for learning engineering in the university using Cooperative Problem Based Learning (CPBL). Among first year Chemical Engineering students in UTM, programming courses are particularly a pain to engineering students. Considering these issues regarding first year students, Introduction to Computer Programming (ICP) course was designed to be integrated with the CPBL problem for Introduction to Engineering (ITE) course. This paper aims to present the integration CPBL problem in both ITE and ICP courses and examine students' perception on the teaching practice. Students perceived that the integrated problem helped them see the application and usefulness of programming and motivated them to put effort in learning.**

Keywords*— Integrated problem, cooperative learning, problem-based learning, introductory course, computer programming, first year engineering

I. Introduction

Many first-year engineering undergraduates have none or limited exposure to engineering prior to entering university [1] . This lack of exposure is one of the factors contributing to the low level of interest in learning challenging engineering content and developing the necessary professional skills. Consequently, this can result in high drop-out and failure rates [2]. To help first year students understand engineering and learning in a university, introductory engineering courses are typically required, covering various aspects related to learning engineering. For instance, Purdue University offers two 2-credit-hour courses; "Transforming Ideas to Innovation I and II", which are courses designed to introduce students to the engineering professions using multidisciplinary, societally relevant content through explicit model-development activities, engaging students in innovative thinking across various engineering disciplines [3]. Other than that, Nanyang Polytechnic in Singapore also offers an introductory engineering course, which uses Conceive-Design-Implement-Operate (CDIO) approach that incorporates knowledge obtained by the students into engineering practices while at the same time develop vital personal and interpersonal skills, to motivates students to learn engineering [4].

In a large technology-based university in Malaysia, an Introduction to Engineering (ITE) course was developed and implemented since 2005 to support first year chemical engineering students to learn engineering. To develop students' insight and capability towards engineering processes, Cooperative Problem Based Learning (CPBL) is implemented as the teaching and learning approach to solve a sustainable development-based problem. CPBL, which is the infusion of Cooperative Learning principles into the Problem Based Learning (PBL) process, has been shown to be effective for developing team-based problem solving in a typical classroom setting. The current implementation of CPBL in the ITE course for first year chemical engineering students has been proven to instil professional skills and pro-environmental sustainability awareness and behaviour [5].

In an effort to further support the first-year students, a problematic first year course that is important, Introduction to Computer Programming (ICP) was considered for integration with the ITE course. The motivation for the integration is due to the success of implementing CPBL in the ITE course as reported in previous studies [6]. ICP course was considered for integration with the ITE course for several reasons. One of the main reasons is the importance of programming for engineers. In the coming era of Industry 4.0, the use of digital technology has become increasingly infused with day-to-day life; be it in simple, everyday personal activities that were traditionally done manually or complicated working tasks that would be difficult to perform without technological aid [7]. However, many first-year engineering students are not interested in the ICP course despite knowing that computer programming skills are crucial in the current working climate. One of the factors contributing to students' disinterest in the programming course is that they see programming as difficult and thus demotivating [8-10]. The current problems and projects given to students in the programming course originally are simple problems, adequate for students to understand and apply the knowledge gained from the lectures.

On the other hand, these straightforward problems and projects are disjointed and unrelated to real world problems. This deprives the students of realizing the importance of programming as engineers in the real working environment.

The timing of the ICP project is yet another possible factor attributing to the low level of involvement in the ICP course, which normally occurs at the same time as the final stage of the ITE problem. This leads to the students feeling burdened with two different projects that requires reports and presentations that they struggle to handle. The timing of Stage C of the ITE problem, which typically occurs at the same time as the ICP project, makes the students feel overwhelmed by the workload. To overcome these issues, the Stage C problem in the ITE course was designed to integrate programming that is suitable for the ICP course. Setting the ICP project into the ITE problem provides context to computer programming concepts, allowing students to learn in a meaningful way. In addition, combining the ICP project into Stage C of the ITE problem makes the effort time-worthy since students could focus on the same problem while receiving marks in two courses, thus reducing their workload. Therefore, efforts were made to integrate the last part of the ITE problem with the ICP project.

In this paper, the design of the integration between ITE and ICP will be shown and explained in detail based on the principles of constructive alignment, How People Learn (HPL) framework and CPBL. Discussion on students' perceptions based on the course exit survey as well as ICP instructors' reflections are also included to get an in-depth, objective view of the impact that the integration had on both students and instructors.

II. Integrating Introductory Courses for First Year Engineering Students

A. Introduction to Engineering Course

The ITE is a three credit-hour course with a class size ranging from 30 to 40 students. The total number of weeks for instruction is 14 in one semester. This course serves to bridge pre-university education to university life and provide support for adjusting to learning and expectations in tertiary education.

The sustainable development-based problem is divided into 3 stages (Stages A, B and C), to scaffold students' learning [11]. In Stage A, students familiarize themselves with sustainable development and concepts related to the problem, the issues related to the problem locally and internationally, and benchmark efforts regarding the issue in Malaysia against other countries. In Stage B, students design simple data collection and analysis related to the problem. Finally, in Stage C, students propose an engineering solution to the problem. Introduction to Industrial Seminar and Profession (ISP) course is integrated with the ITE course for the purpose of providing scaffolding to students through a series of seminars related to knowledge in engineering particularly on selected learning issues of CPBL problem, delivered by experts from industries, academician and alumni.

Problems chosen for a certain semester will be closely related to current issues and interest of students and the community. This is to engage and immerse students in the problem. For example, there was a year when several areas in Malaysia faced problems in getting clean potable water due to incidents of river pollution. In that semester, the problem, titled "Love our river", was regarding river pollution and conservation. The City Municipality officer responsible for river restoration participated crafting and providing information on the problem, as well gave a seminar on river pollution and conservation efforts during the ISP. During the pandemic, because of increased spending through on-line shopping, the problem chosen was on consumerism.

Students go through the CPBL process for every stage of the problem in the ITE course. The CPBL process consists of the three phases as shown in Figure 1. The five CL principles, individual accountability, face-to-face interaction, appropriate interpersonal skills and regular group function assessment, are integrated in CPBL to ensure a functioning team [12]. The CPBL process allows students to construct understanding on their own before interacting with their teammates to interact and develop a better understanding among them. Meanwhile, instructors play a role as floating facilitators, who circulate from group to group or conduct the overall class sessions. The facilitator serves as a coach to encourage students' participation, provide resources, and monitor students' discussions through the different phases to ensure that they reach the required depth. In a CPBL environment, part of the monitoring, support, and feedback can also be attained from peers, especially team members, instead of solely relying on the facilitator.

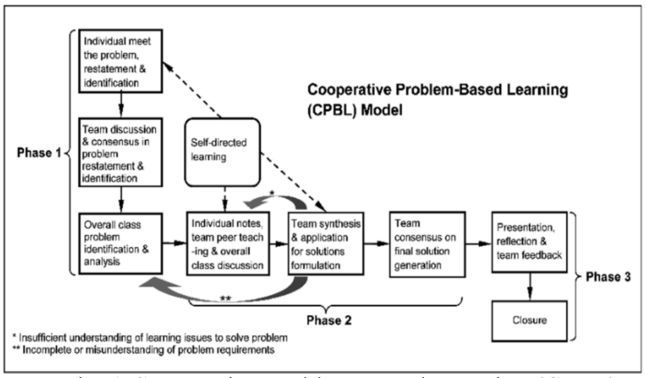

Fig. 1 Cooperative Problem Based Learning (CPBL)

There are three phases in the CPBL process as shown in Fig. 1. In the first phase, students begin by conducting problem identification and problem restatement. The desired outcome of the first phase is to train students' comprehension and ability to restate the problem in their own words, as well as outlining their knowledge by categorizing what they know, what they need to know, and identify the learning issues. Based on the identified learning issues, students find the material for the learning issues and prepare peer-teaching notes in the second phase of CPBL. Through peer teaching sessions conducted in class, students learn together on the learning issues so they can then utilize the newfound knowledge and apply them in formulating the solution to the problem. The final phase of the CPBL process, students develop a solution for the problem and presented it through report writing and oral presentation. Students reflected on the learning process by doing a reflection journal and peer rating. Finally, the instructor gave closure for overall learning concept.

B. Introduction to Computer Programming Course

ICP is an introductory course that provides the students with the foundation of programming skills as a tool for solving

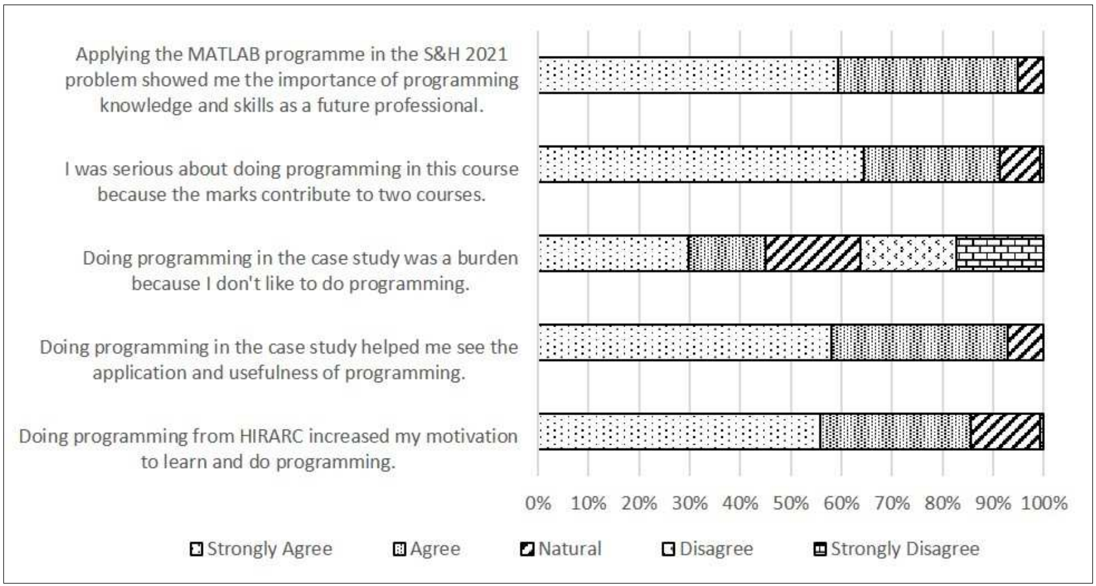

Fig. 2 Students' Responses from Course Exit Survey

problems in chemical engineering. Students are exposed to the basics and application of MATLAB software for solving simple arithmetic operations with arrays, two-dimensional plotting and programming using flow control commands with conditional statements and loops. With this foundation of basic programming skills, the course provides opportunities to explore advanced topics for solving complex chemical engineering problems. In the beginning, students explore the needs and potential applications of programming. Then students are exposed to the MATLAB software and the basic functions. Students are also educated on algorithms and flowcharts before applying them into structured programming. The classes are handled mostly via hands-on learning where students must use the software to learn programming.

In the recent years, ICP instructors have put efforts in introducing a mini project at the end of the semester. Students are also assigned to a group project that starts by the mid semester. The project though does not utilise real-world problem. Students works on the project without really acquiring them to see the application.

C. Design of CPBL Problem Integration with Programming

The design of the CPBL problem for the first-year engineering students begins weeks before the beginning of the semester, as careful planning is essential for the problem to meet various requirements of a suitable, feasible problem. During problem crafting, principles of PBL problem crafting is referred; authentic and realistic, constructive and integrated, suitable complexity, promote self-directed learning and lifelong learning and stimulate critical thinking and metacognitive skills [13]. Thus, among the considerations taken into account when designing the problem is the complexity of the problem, its relevance to the current world issues, the difficulty level for first-year engineering students, scaffolding to be provided by the lecturers, and most importantly, the execution of problem solving that integrates multiple courses to achieve each courses' related course learning outcomes and problem learning outcomes.

In the following year, students were assigned as participants in Safety & Health for All 2021 Competition. The problem for the last stage in the ITE course was crafted to include the ICP course outcomes and teaching and learning activities. Instructors from both courses collaborated on the problem crafting and teaching notes to facilitate students in parallel during both courses. Since programming was introduced in Stage C of the ITE problem, the programming task becomes part of the existing engineering solution for the stage. Students were asked to produce MATLAB program for user application, and subsequently, the result obtained from the application is used in decision making in formulating an engineering solution. The instructors for both courses aligned the instruction and teaching activities to scaffold students in achieving both courses' learning outcomes. The assessment was carried out by lecturers of ITE and ICP lecturers based on the students' execution of the CPBL task that relates to the learning outcomes of the respective courses.

The integration of programming into the CPBL problem in the ITE course has been implemented for two years. The first problem integrated with programming course was on Carbon Footprint for Smart Consumer Campaign. For academic semester 2021/22- Semester 1, the new problem with integrated programming task was introduced. Since classes were being held online, students were learning remotely from their homes throughout the semester. Putting that into consideration, safety and health issue was chosen as subject matter for the problem. The choice of issue that is relevant to the students' current situation helps students put meaning into the knowledge gained by relating with real situation and experiences that directly affect them.

As for the implementation, the integration started to be executed at the end of Stage B. Formerly, the data collection done in Stage B of the CPBL problem in the ITE course aims to find the focus for the engineering solution in Stage C. Prior to the integration of programming, the data collected in Stage B has to be further analyzed and refined to come up with a flowchart. This flowchart acts as a guide to create the

MATLAB program. The result of their MATLAB programming is use for decision making in the Stage C of the CPBL problem.

III. Students' Perceptions

The perception of the students on the problem integration was investigated in the class of 2021/2022 Semester 1. Feedback from 158 first year chemical engineering students were collected at the end of the semester. The questions were developed in a 5-point Likert scale course exit survey;

1. Doing programming from HIRARC increased my motivation to learn and do programming.
2. Doing programming in the case study helped me see the application and usefulness of programming.
3. I was serious about doing programming in this course because the marks contribute to two courses.
4. Applying the MATLAB program in the problem showed me the importance of programming knowledge and skills as a future professional.

General comments from students were also collected to get students' genuine perception in learning through integrated CPBL problem. Students' perception towards integration of programming problem in CPBL assignment were presented in Figure 2.

More than 50% of the students strongly agreed that they realized the importance of programming knowledge and skills by applying MATLAB in Safety and Health problem. Real-world problem makes students aware of the importance of programming towards their career. They could see the importance and needs of computer programming in engineering field from the authentic problem that relates with real life situation, sustainability and roles as an engineer. As mentioned by a student;

"*Correlating both courses allows me to know that programming is crucial and convenient when comes to solving problems*." – Student A

Students' motivation in learning programming is shown from the responses, where more than 80% agree that they were motivated to do programming using safety and health and HIRARC problem. Their motivation in learning programming is a consequence of using engineering problem of CPBL, which is known to be able to motivate students in learning through self-directed learning implemented in solving the intrinsic and real world problem [8]. After introduction to integrated problem in CPBL, students showed positive reactions towards it where they found it inspiring, interesting and enjoyable to solve the problem that involves two courses. Students appreciated the opportunity given to them by putting a lot of effort in completing the task. They could see the importance and needs of computer programming in engineering field from the well-structured problem. Some of the students' comments in regard to their motivation in learning programming are as follows:

"*It's a great opportunity to create a program that related to safety and health in the community, by the knowledge that was gained from Introduction to Programming*." – Student A

"*These courses have increased my interest in the field of my study. ITE and ISP have expanded the horizon and knowledge about the chemical engineering industry, as well as integrated data analytics and programming for engineers in future*." -Student B

"*The integration with Introduction to Programming in generating a program through the database from the audited data showed that as an engineer I should equip the ability to construct a program*." -Student C

On the other hand, it was initially challenging to integrate the project due to the added efforts in adjusting the ICP project to suit the ITE problem, and the uncertainties introduced. However, their observation of students' performance and perceptions at the end of the semester led them to reflect and realize the benefits for students' learning in programming. In the reflection of one of the programming lecturers, she mentioned the changes in students while experiencing this integrated problem;

"*The integrated project allows students to explore MATLAB beyond the classroom. This project encourages them to be creative to solve the problem that they work for ITE class. I can see students produced much more complex MATLAB coding to solve for the integrated project compared to the normal project before. Based on my observation, students worked harder for this integrated project because the outcomes will be evaluated by 2 courses. Thus the impact is bigger, making the students feel high responsibility and motivating them to produce the best MATLAB programming. I think it is also due to the competition and they have the mindset to produce the best to win the project. I can see they put a lot of effort into completing this project when I had one-to-one meetings. I offered team consultation for those who want to seek my advice on their programming. All the teams arranged at least one meeting with me to show / discuss the problems or issues they faced. As a result, they produced MATLAB programs that meet my expectations and I'm very satisfied with their project outcome*." - Programming Course's Instructor A

At the same time, context plays an important role in learning, interacting with motivation and cognitive processes [14]. Real world problems were crafted every year for the CPBL implementation by giving students roles in solving engineering problems and giving them space to contextualize their learning. As defined using constructivist theory, information given by the teacher is important to ensure that learning takes place in such a way that students are able to construct meaning based on their own experiences [15]. For example, in Stage B, students need to conduct data collection and analysis using Hazard Identification, Risk Assessment and Risk Control (HIRARC) which is the basis of occupational safety and health. Students performed data audit by identifying possible hazard, risk and danger at home. Then, they need to analyze the data classifying them by frequency occurred and severity. Safety measures and actions were proposed to eliminate or minimize the risk. Using HIRARC in safety analysis provides context of learning as it was one of the motivations in crafting CPBL problem. The intended learning outcomes are embedded into the problem where concepts, principles or procedures are applied to solve the problem similar as to how they would solve problems in professional practice. Hence, students are trained to adapt

*Fig. 2 Students' Responses from Course E (*this fig had been modified, will replace with revised version later)* themselves into the actual working environment. Prior to the integration of courses through the CPBL problem, students faced problems to contextualize the programming concept through simple problems and memorizing programming code given. In contrast, authentic real-world problems used in the CPBL help students to apply concepts and knowledge in simulated working environments [16].

Based on the exit survey, 44% of students felt that programming task in the CPBL is a burden since they dislike programming. Since ICP is an introductory course, first-year students have either little prior impression on programming or did not have any exposure on programming course. However, students were still able to see application and usefulness of programming through the CPBL problem. The real-world problem provides knowledge-centred environment where it reinforce them to have depth study in understanding the subject matter. Considering students prior knowledge, problem identification and peer teaching activities are supporting learner-centred as explained by Bransford, Brown [17]. Students stated that they were able to improve and strengthen their skills in programming. After solving the problem throughout the semester, they have gained confidence in their ability to apply programming in real applications as quoted from one of the students' comment:

"*This course allowed me to improve in using MATLAB Programming and understand better about Introduction to Programming*."- Student E

However, one of the programming instructors gave input to improve students' performance as quoted;

"*Students are more motivated to do well in the group project, as it is integrated with the project in other courses. Nevertheless, the program given in an integrated project is more defined and rigid, unlike the conventional project, where the students are given the freedom to propose the program which they would like to develop. Thus the creativity of students could be limited*." - Programming Course's Instructor B

Based on the feedback from the instructor, the problem could be improved to be more flexible in terms of the students' solution and decision making. At this point, the integration of courses into the CPBL problem is relatively new, thus necessitating in-depth studies to identify weaknesses and expand on the advantages of the integration to further improve on the problem design and implementation. The current design of the problem, while allowing students to write the codes freely to achieve the purpose of programming, has a clear end goal from the outset. In the case of this semester, the goals of programming are to produce a HIRARC table in Stage B and then to develop a program that enables users to identify the hazard level based on activities done in a specified area within the house. While the initial intention of specifying the goals was to provide students with scaffolding, it can be a double-edged sword; limiting students' creativity and freedom in solving the problem, as observed by Programming Course's Instructor B. Even though the problem crafted enables students to contextualize the learning process, the implementation could perhaps be adjusted to give students more freedom to solve the problem based on their own understanding, instead of being given clear goals to work towards. In order to execute this, problem identification and restatement done in the first phase of CPBL becomes increasingly vital as students need to properly and deeply understand the problem to come up with a suitable solution. Naturally, proper scaffolding needs to be present throughout the process so that students do not stray off course.

Despite a few shortcomings, by integrating knowledge from multiple disciplines, students found valuable ways of understanding knowledge or concepts learned. The ways of knowing influence a student's willingness and skill to argue, to work cooperatively, to take on others' perspectives, and ultimately to comprehend and solve the problem. The most direct factor contributing to the students' motivation is the large contribution of marks from the problem towards the two courses, as agreed upon by 91.3% of the students who answered the Course Exit Survey. Additionally, the integration of courses into one problem has additional subtle impacts on the students as well, which goes beyond students' marks. From the Course Exit Survey, the majority of the students were able to contextualize programming knowledge and skills to practical applications in real world problems and consequently highlighted the importance of programming knowledge and skills as future engineers (92.8% and 94.9%, respectively). From these responses, it is believed that the students' intrinsic motivation, that is, the inclination to master the subject and gain satisfaction from learning, have grown exponentially compared to the students' extrinsic motivation, which is driven by grades and competition. Similar findings were observed by [8].

As for the programming lecturers, their reluctance was apparent in the beginning of the implementation due to the lack of confidence in the benefits of integration of programming into the CPBL problem and the hassle of designing and adapting the ICP project to suit the integration. However, from the clear improvement in students' performance, motivation, and interest in programming due to the integration of programming into the CPBL problem, programming lecturers became convinced in the many benefits of integration of programming into the CPBL problem, as evidenced by their observations on students' increased desire and motivation to learn and seek knowledge on their own accord, as well as the programming lecturers' eagerness to provide feedback and ideas on improving the implementation of integrated CPBL problem.

IV. Conclusion

The integrated introductory courses was intended to resolve issues regarding interest in the programming course for first year engineering students. The students' perception in integrated programming assignment in CPBL problem yielded positive impacts towards students in learning programming By incorporating programming into the real world problem in ITE, most of the students perceived CPBL learning environment in learning programming and develop confidence in understanding the concepts through real situation and realize the importance of programming in real world. This small-scale teaching practice can take place using CPBL to build confidence in engineering educators before moving on to course integration at programme level.

Acknowledgment

The authors would like to thank the Ministry of Higher Education Malaysia and universiti Teknologi Malaysia for supporting this work through the Consortium Excellence Research Grant JPT(BPKl)1000/016/018/25 (59) under the cost centre number R.J130000.7809.4L935

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