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INTRODUCTION TO ENGINEERING PROGRAMMING WITH PROBLEM SOLVING PRACTICE ON COMPUTER AND ARDUINO BASED EMBEDDED SYSTEM

Abstract:

The first semester year one module Introduction to Engineering Programming (IEP) for the School of Electrical and Electronic Engineering (School of EEE) in Singapore Polytechnic (SP) has been revamped from the previous Structured Programming which taught students computer programming on PC in C++. The IEP module learning objectives are: to learn the basics of computer programming on PC; to learn the basics of programming on simple embedded system; to apply the programming knowledge in designing and implementing simple engineering applications that run on computer and simple engineering applications that run on basic embedded system. Students are taught computer programming in the first half of the module to build foundation with hands-on practice in engineering application. In the second half of the module, programming on basic embedded system is added with hands-on in engineering application using hardware. At the end of the module, students design, implement and demonstrate working software program running on basic embedded system as a simulated solution to a United Nation Sustainable Development Goals (UN SDGs)(United Nations, 2023) related problem identified by the students, which serves as school of EEE students' first experience to various stages of engineering (software) design process and exposure to the Conceive-Design-Implementation-Operation (CDIO) framework.

The first run of IEP module in semester 1 of the 2022-2023 Academic Year (AY) showed that students were able to cope programming on both PC and basic embedded system. Students were satisfied that they could see how electronics worked with coding, especially they could apply the programming skill acquired in the module to develop an engineering solution to real life problem.

Keywords:

Computer Programming, Engineering Programming, Engineering Application, CDIO

JEL Classification: I23

Introduction

There are around 580 freshmen enrolled to School of EEE at SP per academic year. Most of them have no prior knowledge of programming and electronics. In their first semester of year one, all the students from School of EEE of SP need to take common modules: IEP, Digital Electronic (DE), Principle of Electrical and Electronic Engineering (PEEE), etc., and 3 common core modules offered by School of Life Skills & Communication (LSC): Thinking Critically about the UN SDGs (TCU), Problem Solving with Creative & Computational Thinking (PSCCT), Collaboration in the Digital Age (CDA),

IEP module teaching and learning schedule could be carefully planned to tap on the incoming knowledge from domain modules DE, PEEE and common core modules, like TCU, etc. to benefit students IEP learning.

Notes: The word "module" in Singapore Polytechnic is equivalent to “subject” in universities.

Module Overview

IEP module is a 4 credit unit (CU) module, consisting of two 2-hour sessions of face to face (in-person) integrated tutorial with practical in the campus physical Lab venues per week. Per semester, there are altogether 15 learning weeks including assessment. Since the COVID-19 pandemic, lectures for all school of EEE modules have been stopped. Instead, there are byte-sized voice over presentations and / or videos prepared by the teaching team for each topic which are posted onto the module website on the SP Leaning Management System (LMS). Students could fully make use of the byte-sized learning materials to start to learn each topic before the topic session begins and do revision if in doubt after the topic session ends.

Table 1 shows the teaching and learning schedule in the full semester for its first run in AY2022_2023 semester 1.

Table 1: IEP teaching and learning schedule AY2022_2023 semester 1 (below)

Table 1: IEP teaching and learning schedule AY2022_2023 semester 1

Week	Two Sessions Integrated Tutorial with Practical	Topic Quiz	
1	**Topic 1** *Computer Programming*	1	
2	**Topic 2** *I/O & Data Types* **Topic 3** *Operators*		2
3	**Topic 4** *Control Statement -- Selection Constructs*	3	
4			4
5	**Topic 5** *Control Statement -- Iteration Constructs*	5	
6	**Lab Test** **Mid Module Quiz**		
7	**Mid Semester Test Week (No MST for IEP)**		
8—10	Term Break		
11	**Topic 6** *Functions* IEP Project Briefing		
12	Brief Introduction to Embedded System **Lab 1 on Basic Embedded System (with LEDs)**	6	
13	**Topic 7** *Array & Strings* **Lab 2** (Part 1) **on Basic Embedded System (with buttons, knob, Light Dependent Resistor, serial monitor)**		
14	Identify and Craft IEP Project Problem Statement		
15	**Lab 2** (Part 2) **on Basic Embedded System (with buzzer, 7-segment display, temperature / humidity sensor, IR remote controller)** **IEP Project Design** **Topic 8** Bitwise Operations (SDL)	7	
16	**End of Module Quiz** **IEP Project Implementation**		
17	**IEP Project Implementation**		
18	**IEP Project Implementation /** **IEP Project Assessment with Demo and Interview**		

Source: IEP module teaching and learning plan

Overall, there are two hands-on assessments: Lab Test (on computer programming) and Project (on basic embedded system); two major online assessments: Mid-Module Quiz and End Module Quiz (on computer programming). The graded Topic Quiz for each topic (except for Bitwise Operation, with reason explained in the next part) is an open book test with multiple attempts allowed within the scheduled two weeks' time. Each Topic Quiz has 5 questions randomly generated from a pool of 20 questions of different types: true or false, multiple choices, multiple answers. The graded Topic Quizzes aim to encourage students to practise more in their own time to gain better understanding and comprehension of the topic.

The IEP module learning objectives for students are:

(1) to learn the basics of computer programming on PC
(2) to learn the basics of programming on simple embedded system
(3) to apply the programming knowledge in designing and implementing simple engineering applications that run on computer and simple engineering applications that run on basic embedded system

C++ is used in IEP teaching and learning. Though based on internet resources (Stephen Cass, 2021, 2022), the current top programming language is Python, C++ maintains a very close second or third. In fact, 3 of the top 4 programming languages of 2021-2022 are in the "C++ family" sharing similar syntax. In addition, with C++ foundation, it's much easier for students to move to Python.

The basic embedded system used in IEP is Arduino UNO R3 or its compatible with plug-in. The reason to choose Arduino UNO or compatible board for this beginner level module is that it is cost-effective, robust, open source, widely used with an active community of educators and hobbyists sharing content and experience online (Arduino UNO Rev3). The plug-in chosen is Rich Shield due to its low-cost, beginner oriented rich Input / Output (I/O) expansion and ready to run examples with installable library (Rich Shield). Below are the outline of Rich Shield and its PINs.

Figure 1: Rich Shield with Infrared (IR) Remote Controller

Source: Rich Shield vendor

Table 2: Richshield analogue and digital pins

Analog pins		**Digital pins** /* ~ denotes PWM pins */	
A0	Blue Knob/potentiometer	D0	Rx
A1	NTC Temperature Sensor	D1	Tx
A2	LDR	D2	IR Receiver
A3	External voltage Source (Voltage Divider) 180k/(180+820) k = 0.18 ratio	D3~	Buzzer
		D4	LED1 (Red)
		D5~	LED2 (Green)
A4	SDA (Connect to EEPROM 24C02ASN)	D6~	LED3 (Blue)
		D7	LED4 (Yellow)
A5	SCL (Connect to EEPROM 24C02ASN)	D8	KEY0 (K1)
		D9~	KEY1 (K2)
		D10	CLK (for LED Drive Control Special Circuit TM1637)
		D11~	DIO (For TM1637)
		D12	DHT
		D13	Uno Inbuilt LED

Source: IEP Lab and Project Guide to get students familiarized with the use of Rich Shield and its libraries provided by the vendor.

The following sections will elaborate in more detail how IEP learning objectives were achieved in the module first run AY2022_2023 semester 1.

Basic Computer Programming on PC

As shown in Table 1, in term 1 (week 1—6), teaching and learning activities focused on programming foundation starting from brief introduction to computer architecture, I/O, memory, algorithm design in flowchart and pseudocode, software design process, and variable declaration till topic on control statements.

Each student of School of EEE, SP has their own Laptop, thanks to the various financial assistance available to the students. It is compulsory for students to bring their own laptop for every IEP lesson, which makes teaching and learning, especially debugging students code more efficient. In a particular class, when there were students not fit for face to face lesson in campus, e.g. not fully recovered from illness, but fit and wish to attend online lesson from home, teaching staff usually conducted the lesson in hybrid mode, e.g. sharing teaching slide and

source code in Integrated Development Environment (IDE) on teaching Laptop via team collaboration software, e.g. Microsoft Teams, Skype, Zoom, etc. with explanation concurrently to students both in the campus Lab and online at home. Students at home could also raise questions when in doubt, just like those in the campus Lab venue did.

Term 1 teaching content could be smoothly delivered with the objective achieved, which was reflected in the results of Lab Test and Mid-Module Quiz conducted in week 6, shown in Table 3 below:

Table 3: Term 1 IEP students assessment performance AY2022_2023 semester 1

Term 1 Assessment Components	Percentage of Students Scoring Below 50 out of 100	Percentage of Students Scoring 70 and above out of 100
LAB Test	5.5%	78%
Mid Module Quiz	9.5%	64%

Source: IEP module students assessment result AY2022_2023 semester 1

In term 2 (week 11- 15), topics on Function, Array and String were taught. Meanwhile, basic programming on simple embedded system was introduced, which will be elaborated more in the next section.

There are engineering applications examples with source codes and practical questions for basic computer programming on PC, e.g.:

- Design an algorithm to find the area of a right-angled triangle using pseudocode and flowchart.
- Write a program to read in a temperature value from the keyboard and display the status of water at that temperature.
- Write a program that calculates and displays the equivalent resistance of two resistors connected either in series or parallel. The values of the two resistors and connection type are to be entered by the user from keyboard.
- Given formula: Gain = $1/(2\pi fRC)$, write a program, which prompts the user to enter the values of the resistor (R) and the capacitor (C), then calculates and displays a table of *frequencies* and *Gains* for frequencies from f = 0.1Hz to f = 1GHz in decade steps (i.e., for each iteration, the frequency is multiplied by 10).
- Design a function to return the weight on moon based on the weight on earth passed on as parameter. In main function, call the designed function and display the weight on moon.
- Design functions with array as one of the parameters to perform simple data analysis:
    - design a function to capture user entered data into an array using for-loop;
    - design a function to find out and return the biggest value of the elements in an array using while loop;
    - design a function to count and return the total number of 0 in the elements of an array using do while loop;
    - call the above functions in main function one by one to display the biggest the value and total number of 0 entered by users.

The engineering applications examples with source codes and practical questions for basic computer programming on PC were carefully designed in the previous Structured Programming module by tapping on the incoming knowledge from EEE domain modules taken by the students

in the same semester, like, DE, PEEE, etc. This part of teaching and learning content was kept in IEP module.

Due to time constraints, the topic Bitwise Operation was delivered as fully Self-Directed Learning (SDL) content. To reduce the workload of students, the topic quiz for Bitwise Operation that was initially scheduled during week 15 and 16 had to be cancelled due to multiple assessments during this period.

Basic Programming on Simple Embedded System

This part of teaching and learning content was newly added to the previous Structured Programming modules and formed an important part of IEP module, which made more sense to EEE students and helped EEE students have a smoother promotion to the next stage.

As shown in Table 1, the basic Programming on Simple Embedded System was only taught in term 2. This differed from other Higher Learning Institutions which taught it at the beginning at the semester (Jillian Beth Schmidt, 2018; Brian M. Wood Alexander O. Ganago, 2018; Michael Daugherity, 2019; Afsaneh Minale, Reza Sanati-Megrizy, 2016). The reason was that most 1st year School of EEE, SP students graduated from secondary school with O level certification and as such did not have an electronic and programming background. In their 1st semester of SP, the students started to take EEE domain foundation module DE and PEEE, concurrently with IEP. With term 1 EEE foundation built from domain modules, it was appropriate to conduct a brief introduction to Arduino based basic embedded system to IEP students in term 2.

The Lab kits were only available in campus Lab venues and not for students to loan out for further exploration in their own time. Vendor info for Arduino UNO R3 and its plugin Rich Shield used in the Lab kits with education discount was provided to the students, in case any of them was interested to buy the hardware sets to practise further in their own time. However, buying the IEP hardware Lab kits was not made compulsory to avoid increasing the financial load to the students, who already had to purchase Lab kits for other modules in the same semester.

In term 1, students had time to learn both at campus and at home, and practise more in their own time on their own Laptop for IEP. Programming foundation built in term 1 helps term 2 function and array topic learning on computer and basic programming on simple embedded system.

Teaching basic programming on simple embedded system started in the 2nd week of term 2, after the topic Function in computer programming had been completed. Students could better understand the statements inside the default two functions of Arduino code: void setup() and void loop() from the function structure point of view:

- which function is called
- what value(s) is / are to be passed on to the parameter(s) of the function, if any
- what's the return value and its data type, if any

Those statements inside the default two functions of Arduino code are usually the calls of Arduino built-in functions, like:

- void pinMode(int pinNumber, int mode)
- int digitalRead(int pinNumber)
- void digitalWrite(int pinNumber, int value)
- int analogRead(int analogPinNumber)
- void delay (int duration_in_ms)

- etc.

Domain module foundation built in term 1 from DE and PEEE not only made the brief introduction to IEP hardware kits including most of its components much easier for IEP students to understand, but also helped students understand the purpose of the statements and link the statements to the status / change of the basic embedded system.

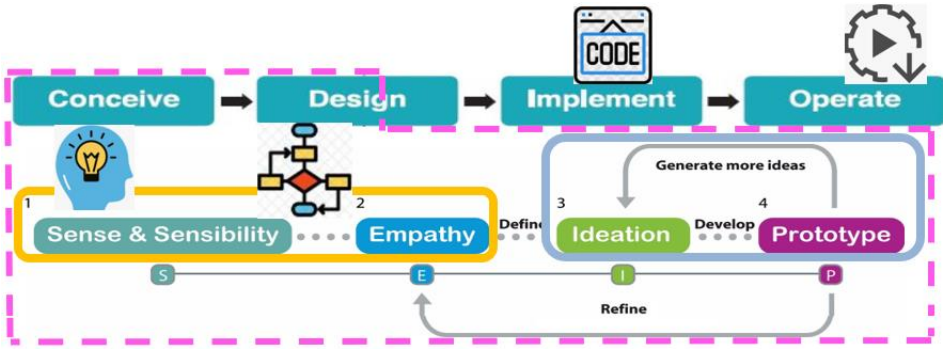
The sample activities in the basic programming on simple embedded system designed by module specialist came with clear instructions and concise explanation of the code. The sample activities not only served as self-guide for students to follow and complete the hands-on coding task(s) on simple embedded system, but also served as revision of the knowledge obtained from computer programming part.

After each sample activity, there were usually more than one practice (with hint but no more detailed step by step instruction) in engineering application from which students could choose the one(s) closer to their IEP module project for further practice. For example, after the default Arduino blink LED sample activity, one of the practices was to write Arduino program to blink red LED to simulate emergency flashing lights. Students were required to design a function to blink a LED with LED color, blinking duration and blinking times as parameters, then call the user designed function, instead of just calling built-in Arduino function to simulate emergency flashing lights. Students were also required to draw block diagram to indicate what I/O component(s) / device(s) in the Lab kits were used together with the Microcontroller to implement their solution; students were required to create flowchart for the algorithm before starting to code. The software design process stages were embedded in the activities. The practices after the sample activities not only served as more practice in programming on simple embedded system, but also served as preparation for students IEP project.

Module Project -- Developing a Simple Simulated Solution to a UN SDGs Related Problem Using Basic Embedded System

The IEP project was briefed to students by teaching staff in the 2nd week of term 2. Students were paired to observe and identify problem related to UN SDGs, and conceive an idea, design a partial solution to the identified problem, and implement the solution (in simulation) on basic embedded system. The CDIO sequence was briefly illustrated in the module project description, as screenshot in Figure 3, to give the 1st year 1st semester IEP students an appreciation of CDIO, the innovative educational framework for producing the next generation of engineers (CDIO Standards 3.0):

Figure 3: Brief CDIO sequence illustration in IEP project



Source: IEP module teaching and learning materials

The IEP module project required students to identify UN SDGs related problem which could be partially solved using basic embedded system. As part of project assessment, each project group needed to prepare and submit one copy of their IEP project report. In the IEP module project report, students needed to record their work in various software design process stages: the identified group project problem statement relevant to UN SDGs, block diagram showing the input and output of the Lab kits used in their solution to the identified problem, flowchart of the algorithm, including the flowchart of user designed function implemented in the solution by each member, individual contribution and the URL of the short video demonstrating their group project. Source code of the group project had to be included with the project report and submitted to module website before the project interview started.

Students' knowledge gained from the 3 common core modules TCU, PSCCT and CDA helped them in their IEP module project from UN SDGs related problem identification, problem statement crafting, idea conceiving, to flowchart designing.

IEP settled on a project team size of typically 2 students, which matched well with the project workload and tasks to be completed. The teams were formed, mentored by IEP lecturers to ensure that the students received timely feedback on their performance and got help when needed so as to make sufficient progress in implementing their solution on the basic embedded system used in IEP module.

Due to limited I/O and function provided by the Lab kits and limited time allocated for the IEP project, students only needed to implement partial solution in simulation and demonstrate their working solution on the basic embedded system to the lecturer with interview questions to check student understanding during scheduled IEP lesson time by week 18.

Table 4 showed the assessment data in term 2 of AY2022_2023 semester 1.

Table 4: Term 2 IEP students assessment performance AY2022_2023 semester 1

Term 2 Assessment Components	Percentage of Students Scoring Below 50 out of 100	Percentage of Students Scoring 70 and above out of 100
End Module Quiz	31.3%	25.7%
Project	3.2%	75.6%

Source: IEP module students assessment result AY2022_2023 semester 1

The term 2 assessment results showed that though relatively high percentage of students did not do well in End of Module Quiz, they could apply what they learnt in computer programming to programming on basic embedded system and develop a simple simulated solution to part of the UN SDGs related problem identified by the students.

The module overall passing rate for AY2022_2023 semester 1 was 99.5%.

Discussion

All the assessments of the module were set to meet the academic vigor and the results were satisfactory, except for the End Module Quiz with relatively high failure rate.

The major reason for the high failure rate of End Module Quiz was that its focus was the hardest topics for beginners: Function and Array (for computer programming), and there was only one week allocated for students to prepare for this assessment. At the same time, students still had Lab activities to complete on basic embedded system. To schedule End Module Quiz one week

after Topic 7 but two weeks before project interview was to allow time for students to revise for the assessment, though only 1 week, then concentrate in their IEP module project to avoid possible confusion of computer programming and programming on embedded system due to the differences of input and output on PC and embedded system. For example, for computer programming, cin is used to capture input from keyboard, cout is used for display output to the screen; while on the Arduino based basic embedded system, function int digitalRead(int pinNumber) is used to read input from a digital pin, like the one connected to button or switch, function void digitalWrite(int pinNumber, int value) is used to write to a digital pin, like the one connected to LED, buzzer, motor, etc.

Considering the short revision time given to End of Module Quiz, the possible action plan to address the relatively high failure rate of End of Module Quiz includes: to provide hints to the questions students answer wrongly in the Mock End of Module Quiz, to add more foundation and application questions for difficult topics Function and Array in Mock End of Module Quiz pool to drill students more.

Though students were able to apply what they learnt in computer programming and develop a simple simulated solution to part of the UN SDGs related problem identified by them using basic embedded system, both students and staff feedbacked that it could be better if there was more time for students to use the IEP Lab kits for the module project.

The utilization of Lab venues for IEP was relatively high. The teaching and learning schedule was relatively tight after adding programming on embedded system. To address the time and venue constraints of student using IEP Lab kits, it is proposed to have a separate Lab venue with IEP Lab kits dedicated for student free access during IEP project development weeks.

Due to limited I/O and function which the current IEP Lab kits could provide, students could only provide partial solution in simulation to some of the identified the UN SDGs related problem. Design our own Lab kits with IoT function and more I/O is in the agenda of module specialist's exploration.

In the module review, teaching staff feedbacked that Topic 8 Bitwise Operation should be included in the assessment as it is an important knowledge in embedded system, despite tight schedule after introducing programing on embedded system. In the AY2023_2024 run, Topic 8 Bitwise Operation is still an SDL topic, but to be shifted to week 6 with its topic quiz opened from week 6 and closed till the end of the first week of term 2, so that students could have enough time to self-study the topic, and complete the topic quiz.

Conclusion

The first run of IEP module with 580 students from School of EEE, SP in AY2022_2023 semester one was successful with satisfactory module overall passing rate and largely positive module feedback from students.

IEP module students were able to cope with learning programming for both PC and basic embedded system; at the end of the module, students were able to apply the programming skill acquired in developing a simple simulated solution to part of the UN SDGs related problem identified by them using basic embedded system. Module objective was thus met.

Students went through various stages of engineering (software) design process in the weekly hands-on exercises / activities and module project. Students also gained appreciation of CDIO approach through their IEP module project.

The foundation built in IEP module will benefit the students in transition to their next stages' modules, like Microcontroller Application, etc.

Based on the feedback from teaching staff and students of IEP in its first run in AY2022_2023 semester 1, there was a need to adjust the teaching and learning schedule so as to give students more time for topic Bitwise Operation. A dedicated Lab venue could be prepared for students' free access during the critical module project development period, e.g. week 17.

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