Designing an Autonomous Vehicle System Design Course for COVID-19 Remote Learning under First Principles of Instruction Framework

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***Abstract*—In order to cultivate the expertise in developing autonomous vehicles (AVs) in the future, there is an emergence of courses on holistic AV system design for undergraduate engineering students. This paper presents the design, implementation and evaluation of a cross-disciplinary AV system design course developed under the First Principles of Instruction (FPI) framework. FPI-guided learning design facilitates students to learn effectively due to structured coverage of activation, demonstration and application in their learning when developing the product. Through the guided development, the developed course should facilitate students in developing a well-constructed and productive AV system, and cultivate students' holistic engineering competencies (e.g. creativity, problem solving). From survey responses, students held more positive perceptions towards the courses' objectives. Instructors' observations on artefacts produced by students also revealed that learners acquired high-order thinking skills and psychomotor skills after completing the course. This paper also discusses how the course can be re-designed in the second cohort for remote learning during the COVID-19 period, such that students can learn even if they cannot physically access the workshop studio and attend workshop training.**

Keywords—First Principles of Instruction, instructional design, autonomous vehicle system, cross-disciplinary, COVID-19

I. Introduction

Under the growing trend of developing smart city infrastructure, cutting-edge technologies (such as artificial intelligence and sensor systems) have been adopted to automate transportation. For example, autonomous vehicle (AV) systems [1] were empowered to interconnect with each other and move autonomously to serve requests from both human and machines. For sustainable development, the AV industry is training up more experts to participate in developing AV systems [1]. In order to cultivate the expertise in developing AVs and other related cross-disciplinary applications in the future, there is an emergence of modules and courses on AV system design for undergraduate engineering students.

Designing instructions for cross-disciplinary engineering project modules often aims to enhance student's creativity and develop their holistic engineering competencies. However, traditional project modules limit students' motivation to pursue a discipline due to inadequate learning hours for project development [2], lack of industrial exposure for more inspiration [1], and shallow coverage of self-reflection to substantiate students' learning experiences [3]. Some courses associated with AV system design argued that learning-by-doing allows learners to apply the concepts acquired from lectures and manuals for resolving real-life problems and challenges [4]. However, how the learning design aligns with, and benefits engineering skills acquisition have not been clearly addressed and explained in the current literature. In particular, there is no proper instructional design framework for assisting teachers in systematically developing AV design courses and cross-disciplinary integrated engineering courses.

Recently, after a feasibility study [5], the Department of Electrical and Electronic Engineering in the University of Hong Kong has designed a cross-disciplinary course on designing AV systems, in order to equip students with the skills for handling integrated design projects in the future. As the course leader planned to experiment with the usefulness of better learning design for the new course, the teaching team has adopted Merrill's First Principles of Instruction (FPI) instructional design framework for guiding the design of courseware and learning activities. From survey responses, students held more positive perceptions of achieving courses' learning objectives. Instructors' observations on deliverables also revealed that learners acquired high-order thinking skills and psychomotor skills after completing the course.

This study features the journey of designing and implementing the course, according to principles stated in the FPI framework thereafter. This study would address the following research questions through collecting and analyzing survey, interviews, performance and student artefacts:

- How should an AV system course be designed, for a good students' perception and effective achievement of learning outcomes?
- What is the efficacy of adopting the FPI or instructional design framework for developing engineering courses?

FPI and the course are briefly described in Sections II and III, respectively. Section IV describes how the FPI framework was adopted in the course design that can facilitate student development of psychomotor skills and thinking skills. Finally, an evaluation of the effectiveness and impact of the course is shown in Section V. Section VI discusses how the course can be re-designed in the second cohort for remote learning during the COVID-19 period, such that students can learn even if they cannot physically access the workshop studio and attend workshop training.

II. First Principles of Instruction

A systematic instructional framework is recommended for equipping students for creative and practical endeavour [7]. However, there is not much prior literature on applying instructional design in engineering education. Rüütmann and Kipper summarized different direct and indirect instructional tactics in engineering education [7]. It mainly covers the necessary actions for developing and executing a teaching session to enhance learning engagement. Meanwhile, Lim and Kim implemented FPI for adopting the approach of flipped classroom in engineering education while they adopted the FPI principles in post-class activities and solving real-world problems [6]. In contrast with the usual practices in teaching AV system design, their instructional design enforces learners to discover and resolve their own real-world problems after the instruction rather than solving pre-defined real-world issues. However, we believe Lim and Kim's and implications from comparable studies are still discussed in a generalized manner such that a more rigorous exploration is required in yielding practical design implications from adopting Merrill's First Principles of Instruction (FPI) [8] framework in engineering education [6].

The FPI framework consists of five major principles and 15 associated corollaries that can enhance the effectiveness of delivering instruction. It can be applied for course design, courseware revision, or behavioural adjustments in teaching. The five principles are shown as follows:

- **Principle 1 - Problem Centered**: Learners are guided to solve problems that must exist in real life.
- **Principle 2 - Activation**: Activating learner's existing knowledge is required for new knowledge as a foundation.
- **Principle 3 - Demonstration**: Adequate, relevant and comparable guidances are clearly perceived by the learner to achieve the learning objectives (LO).
- **Principle 4 - Application**: Practices and post-tests are sequenced and varied, with consistency with the LOs.
- **Principle 5 - Integration**: Learners should be able to integrate knowledge into daily life and can publicly demonstrate their own skills clearly without doubts and hesitation.

Comparing the FPI to other instructional design frameworks, we believe that FPI 1) has a higher efficacy in improving learning design of the course, and 2) can effectively facilitate students' acquisition of necessary engineering skills through the project. Therefore, we adopted the FPI for improving the design and development of a designated engineering course. Due to space limit, corollaries of the FPI principles can be found in the original text by Merrill [5, 8].

III. Course Overview

The course is a core advanced-level course for undergraduates from Computer Engineering, Electronic Engineering and Electrical Engineering majors, entailing the following intended course LOs, under the mastery-based learning curriculum:

- Master the design principles of a modern integrated system.
- Master the techniques of designing and implementing practical electronic systems.
- Master the use of a microcontroller (e.g. Arduino) and tools for building practical electronic systems.
- Master the techniques of problem solving and group project management.
- Master the skills of applying innovation to develop novel applications.

The course contains three pre-laboratory lecture videos (10-12 minutes each), hands-on laboratory activities and assessment activities that take place throughout the whole semester (13 teaching weeks). Similar to other flipped classroom implementations, students are required to watch videos on basic concepts and skills on their own, so that they can be prepared before attending laboratory sessions. A site visit to an industrial plant is conducted, such that students gain comprehensive industrial exposure to the usage of AVs.

In the five laboratory sessions, the following sub-topics have been covered for AV system development:

1. Microcontroller: Learners use Arduino to program the microcontroller for operating specific electrical devices (lights, sensors and motors) that may require in building an AV vehicle. This module assumes learners are familiarized with basic programming statements (variables, functions and loops).
2. Ultrasonic and infrared sensors: Students manipulate them and to create a circuit with timed instructions that operates devices such as buzzer and small monitors, which are useful in monitoring the behaviour of the AV.
3. Servo motor: Learners first control the potentiometer for understanding the changes of the servo motor. Then they construct a light tracker to control the servo motor instead. The exercise allows learners to condition the input and output signals for operating the servo motor on AV.
4. Photovoltaic module (PV) and its application to wireless charging for powering the AVs: Learners firstly create a circuit with PV for acquiring the change of voltage and current under various light intensity and its associated technical concerns for charging the AV.
5. Communication protocol between Wi-Fi chips and sensors of Arduino devices: Learners first create two Arduino devices with the Wi-Fi chip installed. Then they prompt the two devices to exchange their identification profile and distance through both the Wi-Fi chip and the ultrasonic sensors.

After attending laboratory sessions and joining the site visit, as their project assignment, students have to build their own AV system prototype in a group of four to five students. Eventually, they have to demonstrate their prototype with a pitch video. Students have to complete post-class reflection tasks for most of the activities.

IV. COURSE DESIGN UNDER THE FPI FRAMEWORK

The design principles, engineering skills, LOs, teaching and learning activities (TLA) and assessment activities are inter-related. Therefore, the process for course design can be summarized by the following steps:

1. Identify the significant engineering skills for developing student's own skillset.
2. Determine if there is alignment between these skills and the predesigned LOs. Rewrite the LOs if the alignment is unsatisfactory.
3. Draft the TLAs and assessment activities upon the proposed LOs.
4. Review the instructional content and materials of the TLAs according to the selected instructional design framework. The draft content (e.g., text, visuals) of each task are revised if they do not follow or are inconsistent with the framework.

In this study, the preliminary design of teaching and learning activities was reviewed according to FPI items outlined in Section II and their corresponding corollaries [8].

A. Designing Laboratory Activities

In order to equip students with the necessary skills for building AV systems, students have to explore the use of electronic devices and sensors in five laboratory sessions before working on the project. The following exemplifies how the laboratory activity instructions can be revised based on **Principles 1, 2 and 3**.

1) Designing LOs of the Laboratory Activity

Existing studies suggest non-prescriptive and unstandardized LOs enhances students' learning processes [12]. Therefore, we designed the LOs of each activity through FPI, such that they signal both instructors and learners that there is no ambiguity in aligning the learning tasks and the objectives. By referencing the FPI, the drafted LOs are rewritten to align with the TLA. We have proposed the following approaches for revising the LOs:

- Identify if redundancy and unclearness are found in original LOs.
- Analyze and change the action verbs with reference to the Bloom's Taxonomy.
- Analyze and change the part following the action verb to follow FPI principles and corollaries.

An example of how the LOs can be rewritten is shown in Table I. The laboratory exercise is about developing communicative Arduino devices for AV systems. Upon analyzing these LOs in the draft laboratory notes, we found that they are written at an abstract level, which does not fulfil the "Show task" corollary in the FPI[1]. For example, the phrase *"to use ESP8266 for network access"* is ambiguous and could lead to several interpretations, and thus confusing learners (e.g. *"What would be the task for using ESP8266 for network access?"*). Therefore, the outcome was revised to help learners recall the whole data exchange process.

TABLE I. PRELIMINARY AND FINALIZED LEARNING OUTCOMES OF LAB SESSION 1

Preliminary Learning Outcomes		
1. Use ESP8266 for network access 2. Study the MQTT protocol 3. Understand how to exchange data between two Arduinos to develop a prototype of the course project		
	Finalized Learning Outcomes	**TLAs**
1.	Develop a communication system that involves two Arduino devices through the ESP8266 microcontroller with the application of MQTT protocol mechanism.	Program two ESP8266 microcontrollers for publishing messages mutually.
2.	Explain how to exchange data between two Arduinos, to develop a prototype of the course project.	Prompt students to propose better modification to in lab reflective questions.

2) Designing Instructions of the Laboratory Activity

A laboratory on photovoltaic (PV) system analysis is used to illustrate how FPI can be used for designing instructions. In order to discover factors related to the performance of PV cells. Each exercise has been revised with more relevant instruction on conceptual knowledge before executing the task, such that learners can be guided to master the concepts through performing laboratory tasks. Each concept demonstrated strong relevance to the task, such that it can ensure students can complete the task without seeking unnecessary further reference, as illustrated in **Principle 1**. Examples of the revisions are as follows:

- Students might be confused about what factors related to the performance of PV cells should be analyzed if no instructions are given at the beginning. Therefore, explicit instructions were included in order to follow "Show Task" corollary [1]: *"To discover and address such dependencies, we will first: i) create a circuit with PV and the Arduino UNO, ii) inject Arduino codes to start up the voltmeter, and iii) take readings of the voltage (V) and current (I) by varying the resistance (R) with a potentiometer."*
- Since students already learned that "*voltage is directly proportional to current*" in their secondary education, a statement *"The output from a PV cell does not follow that of a constant voltage source (e.g. battery)"* was included, such that existing knowledge can be recalled to construct new knowledge about the PV outputs, which follows the "Previous experience" corollary [2].
- In order to align the task procedure with the task objectives, an instruction was included: "*Connect the ammeter, the Arduino UNO, LCD display and the rheostat to the PV cell.*" However, learners can understand the statement more easily if the relevant wiring diagram is also provided. In order to follow the

[1] *"Show task": Learning is promoted when learners are shown the task that they will be able to do or the problem they will be able to solve as a result of completing a module or course.* [8]

[2] *"Previous experience": Learning is promoted when learners are directed to recall, relate, describe, or apply knowledge from relevant past experience that can be used as a foundation for the new knowledge.* [8]

"Relevant media" corollary [3], the work had been supplemented by schematics showing pin connections between Arduino and the LCD display.

3) Adopting FPI Framework in Practice

The FPI framework was used for guiding the design of all learning instructions and activities. The revised version of the instructional design and practices provided by instructors reveal that instructors naturally incorporated the FPI principles in the preliminary design, as some of these principles are in their usual teaching practices. In general, **Principles 1, 2 and 3** can be quickly adopted through revising instructions and contents. The related learning activities, such as laboratory sessions and site visit reflection, can be revised for aligning with **Principle 4** by using new perceived information and knowledge for AV development endeavours. **Principle 5** (e.g. "Creation" corollary [4]) is challenging to adopt as students may demonstrate their acquired skills through various ways while there may be no standard methods to assess. Further analysis of how these acquired skills could be aligned with contexts in multiple disciplines is warranted for addressing the challenges associated with this Principle.

B. Designing Reflection Questions for the Field Trip Visit

After the field trip visit, students are required to compose a reflection regarding i) what their perceptions on the AV design are, ii) their thoughts about the current AV development in industries, and iii) possible workover for materializing their own AV project. We have incorporated FPI principles into the reflective questions[5], for capturing how well learners can apply their knowledge and skills to their final project:

- Q1: Please identify the major parts and functions of the autonomous vehicle/ selected application.
- Q2: What features of the autonomous vehicle/selected application attracted your interest?
- Q3: Briefly describe any features of the autonomous vehicles that you do not like, and state your justifications.
- Q4: Based on the statement above, what features you would like to add to improve this vehicle?

Q1 asks students to identify major functions of the AV, such that students can recall the event experience (i.e., "Previous experience"). Q2 asks them to describe such experience that drew their attention ("Reflection"). Q3 and Q4 ask them to comment and explain what they do not like, for allowing them to develop their judgement ("Reflection").

C. Designing Team Project and Project Demonstration

A prototype AV system developed by students consists of two cars equipped with Arduino Mega, wireless communication components, servo motors and sensors. Through wireless communication, two vehicles can exchange messages among themselves and/or with a server, and eventually collaboratively perform tasks on a gridded floor (white cardboard with black grid). The prototype is required to complete the following tasks:

TABLE II. PRE-/POST-SURVEY: PERCEPTION ON ACHIEVING LEARNING OUTCOME

Items	Mean (Pre)	SD (Pre)	Mean (Post)	SD (Post)	p-value (Mean)
Master the design principles of a modern integrated system.	3.59	0.87	3.59	1.15	0.9919
Master the techniques of designing and implementing practical electronic systems.	3.53	0.87	4.00	0.92	0.0244 *
Master the use of a microcontroller (e.g. Arduino) and tools for building practical electronic systems.	3.43	0.84	4.03	0.98	0.0053 *
Master the techniques of problem solving and group project management.	3.59	0.83	4.21	0.69	0.0007 ***
Master the skills of applying innovation to develop novel applications.	3.59	0.93	3.94	0.93	0.0888

Note: * $p < .05$, *** $p < 0.001$

- Move to a particular coordinate with obstacles.
- Park the vehicle for wireless charging.
- Identify a potential collision and detour.
- Visit a set of coordinates through multiple vehicles.
- [Advanced] Locates the companion vehicle and follows it with a certain distance.
- [Advanced] Vehicles can be controlled remotely (e.g. through a server).

Based on the "Watch Me" corollary [6], students have to demonstrate what they have learnt and take note of how they should deliver such concepts to outsiders. Therefore, student groups had to produce a one-minute video, to illustrate their project idea and the development process.

V. DEVELOPMENT EVALUATIONS

The effectiveness of this integrated design course development was evaluated by i) students' perception, ii) students' achievement of LOs, and iii) students' development of thinking skills and psychomotor skills.

A. Student's Perception via Student Surveys and Interviews

Students were asked to comment on the quality of the instructional materials, and to explain their development process in designing the prototype, including the thinking process and challenges encountered. Out of 101 students, 31 entrance questionnaires and 52 exit questionnaires were collected. Some insights had been generated based on the data:

[3] *"Relevant media": Learning is promoted when media play a relevant instructional role and multiple forms of media do not compete for the attention of the learner.* [8]

[4] *"Creation": Learning is promoted when learners can create, invent, and explore new and personal ways to use their new knowledge or skill.* [8]

[5] *"Reflection": Learning is promoted when learners can reflect on, discuss, and defend their new knowledge or skill.* [8]

[6] *"Watch me": Learning is promoted when learners are given an opportunity to publicly demonstrate their new knowledge or skill.* [8]

TABLE III. Learners' Belief On Learning Principles

Post-Survey Items (Learners' belief on TLAs with FPI)	Mean	S.D.
You are engaged in solving real-world problems.	3.90	1.05
Your relevant previous experience can be recalled upon completing each small lab task.	4.05	1.01
The instruction truly demonstrates what is to be learned rather than merely telling information about what is to be learned.	3.78	1.16
You actually used new knowledge or skill acquired in the lab to solve upcoming problems.	4.05	1.01
You actually integrated (transfer) the new knowledge or skill into their everyday life/ applications.	3.98	0.93

- An 0.5 increment of the mean in most questionnaire items is recorded, as shown in Table II. The improvement in perceived achievement of LOs implicates most students deemed the LOs as being coherent to what knowledge and skills they were taught and what they learning activities they performed. This also demonstrates the alignment between not only LOs and TLAs but also with the FPI.
- In the collected open-ended responses, some learners mentioned "*The LOs and lab tasks, such as the usage of Arduino, coding guidance, especially in AV networking, are well explained for troubleshooting their AV system design efficiently*".
- The high mean values in Table III show that the teaching and learning activities were effective in realizing the principles, such as resolving real-world problems and connecting prior and new experiences for better integration in the industrial field. Therefore, FPI framework has been successfully adopted for course development in this study.

Therefore, we conclude that the course not only helped students achieve the LOs, but also enhanced their learning experience in congruence with the FPI.

Four students were invited for individual interviews. Based on interview results, students perceived that some topics, such as developing communication system, are worthwhile studying for preparation of their prototype design. They commented that more visual instructions on more straightforward tasks could help them save time in understanding the schematic figures under challenging tasks. This corroborates the "Relevant media" corollary. Students also suggested that more training is needed for teaching assistants, such that they can provide constructive feedback and clear guidance. This suggestion also demonstrates consistency with the FPI "Diminishing coaching" corollary.[7]

B. Students' LO Achievement via Course Grade

101 students were assessed on their technical skills in implementing the prototype. The assessment criteria depends on whether the machine can correctly perform the tasks mentioned in Section IV-C. As illustrated in Section III, a written report and a video were used to assess students' skills on problem solving and group project management. The report should contain the project summary, system description, any changes to the proposal, work distribution and reflections. The video should demonstrate all the performable tasks.

TABLE V. Overall Performance of Students

Items	Max	Mean	S.D.
Lab checkoffs	20	19.61	0.94
Moodle questions	10	7.61	0.90
Laboratory reflections	10	8.73	0.87
Field trip reflections	5	3.76	0.96
Interim evaluation	15	11.80	2.38
Project demo	15	10.97	2.98
Project report	20	16.56	2.39

TABLE IV. An Example of The Problem-Solving Stateemtn

Problem: Misidentification of appropriate line by QTIs

Description: As our grid's scale is same as the rectangular one (the basic one we used), when we have 4 lines intersecting, the intersection area is relatively large. It becomes difficult for the QTIs to detect and recognize which line is the appropriate option chosen by the program. If the wrong line is chosen, the final result of the program would differ.

Solution: Spinning operation's duration has to be measured accurately, for example, the left-turning and right-turning duration for choosing diagonal or rectangular lines. Even a small difference could make the car turning incorrectly. Through several trails to look for the best combination of line follow, the delay time for turning left, right, and forward after detection of the cross were measured accurately. It thus helps with making accurate decision on choosing lines.

Table IV listed the overall performance of students graded by instructors. All students performed better than the instructors' expectations in laboratory tasks, Moodle questions, and reflection reports. Since these items are mapped to LOs, a high score likely indicates that students have achieved LOs well after applying FPI to the course design. However, noticeably lower mean score in both the interim evaluation and project demonstration is found. We noticed that students have not received clear guidance during the interim and project demonstration due to constrained teaching and revising schedule, that resulted in inadequate technical support to the student groups in need. Multiple interpretations and associated responses to student problems among the lab technicians and the teaching team also caused students to misunderstand the laboratory instructions for completing their final product. For example, one of the student groups raised concerns that one of the important components, gravity sensor, which they deemed necessary to complete the final product, was not mentioned in the lab manual, and they later discovered this when seeking help from lab technicians. Another group was concerned about the reliability of the assessment criteria. Whether wireless charging worked, for example, was perceived to be dependent on sheer luck. While the other groups questioned if the grading was partly dependent on the quality of the self-purchasable components. Nevertheless, students' attempt to voice-out for revising and synchronizing the content and guidelines of the laboratory tasks is found to be a validation for fulfilling **Principle 5**, for reflecting what they lack in advancing their AV design skills.

C. Students' Acquisition of Thinking Skills and Psychomotor Skills via Student Deliverables

Students' reflections associated with problem discovery in the development stage have been examined for evaluating

[7] *"Diminishing coaching": Learning is promoted when learners are guided in their problem solving by appropriate feedback and coaching, including error detection and correction, and when this coaching is gradually withdrawn. [8]*

TABLE VI. STUDENTS' SELF-PROPOSED FUNCTIONS FOR THE SMART PARKING SYSTEM

- The system can find out the coordinates of the available parking space with the shortest distance from the entrance of the car park.
- The car can figure out it's coordinates through "detecting" the receiver coil under the board
- The car will then travel to the corresponding location on the board without grid lines.
- The car will record coordinates of the last occupied parking space.
- The WiFi modules can transmit the requested coordinates to the car, then it will reach the corresponding location.

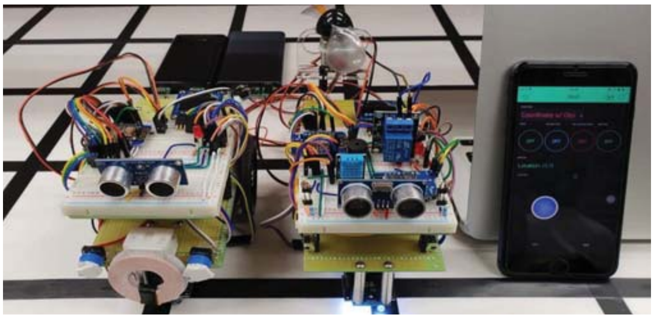

Fig. 1. Prototype of the refined Smart Parking System by IDP students.

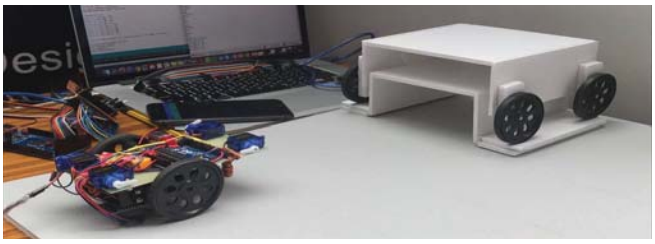

Fig. 2. Smart Parking AV lifting a target vehicle for parking.

whether students demonstrated thinking/evaluating skills. Table V shows an extract of the problems a group encountered, their analysis and how they solved the problem. They documented the event on how errors induced by sensors misguided the vehicle choosing the incorrect path to travel.

Another student group designed a smart parking system that uses the wireless charging coil for indoors positioning purposes, based on the idea introduced by the government [15]. Their design is shown in Table VI and Figs. 1 and 2. Instructors commented that students demonstrated the ability to adopt AV technologies for addressing needs in society, as illustrated by "Creation" corollary [8]. This system consists of an AV with flat-bed exterior design. The target vehicle will firstly park to the position with the parking tray. The AV will then travel across the parking tray underneath and lift up the whole target vehicle by vertically-extensible rods.

VI. COURSE RE-DESIGN FOR COVID-19 REMOTE LEARNING

In face-to-face sessions, students were fully engaged in developing ideas and constructing the resulting product, with test-and-measure equipment and close mentoring support in the university workshop. However, the COVID-19 pandemic has affected educational institutions worldwide. The closure of universities has led to a sudden shift of group design project away from the workshop studio to online learning [12,13]. The COVID-19 pandemic disrupted all face-to-face sessions that affected both learning activities and assessments.

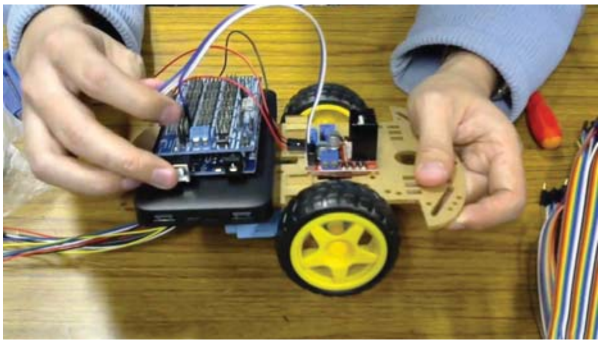

Fig. 3. Assembling the motor, car body and the wiring in the practicum demonstration video during COVID-19 remote teaching.

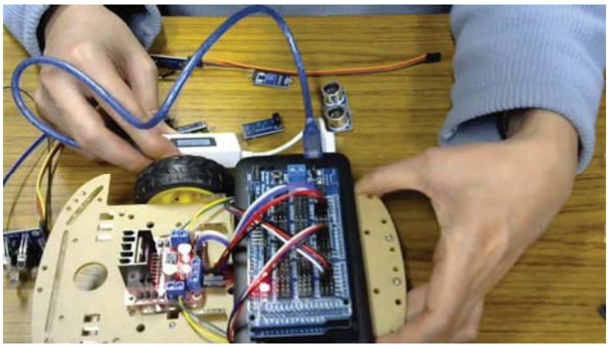

Fig. 4. Measurement of sensor components in the practicum demonstration video during COVID-19 remote teaching.

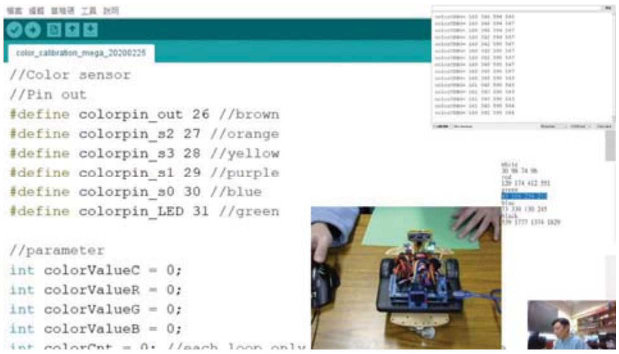

Fig. 5. Color calibration of sensors in the practicum demonstration video during COVID-19 remote teaching, with showing the programming interface, mesurement readings, device movement and demonstrator hands-on demostartion at the same time.

Furthermore, with little preparation, and the challenge of insufficient technical support at home, both teachers and students struggle with online learning. Modifications of the course design in the second cohort have been made to make the learning package accommodating to students who are staying overseas or in quarantine.

A. Redesigning the Labatory Activities

The teaching team has looked through several alternatives in running the laboratory sessions remotely. Zoom meeting was one of the candidate choices while it was found to be inefficient in monitoring the large-sized student groups and their working progress. Instead of holding Zoom meetings, the teaching team asked each student group to collect a package of equipment in the department offices or through mail delivery. In cases of extra support before material collection,

[8] *"Creation": Learning is promoted when learners can create, invent, and explore new and personal ways to use their new knowledge or skill.* [8]

simulator support was provided for basic implementations prior to performing the lab tasks. Documentations and a series of instructional videos were included in these sets for guiding the students in assembling and testing each device featured in the course. In particular, ten videos have been produced which consists of step-by-step assembling instructions with visual guidance. From constructing the vehicle frame (Fig. 3), installing color sensors for detection purposes (Fig. 4), to programming for various movements (Fig. 5). Students can also re-watch the videos back and forth as some of the assembly processes are difficult to follow. **Principle 3** and associated corollaries have been used for guiding the production of demonstration videos.

The instructions had been tailored that some undeliverable complicated equipment had been replaced by alternative approaches and optional tasks. Students who may have doubts and difficulties in completing the tasks were advised to access the discussion forum in Moodle and raise concerns to the teaching team for one-to-one consultations. Short point-of-view-based video assignments can be introduced for assessing students' psychomotor skills in the following cohort.

B. Redesigning the Project Demonstrations

Similar to the arrangements in lab activities, each student group can collect a development package for building their final project. Fully simulator-based individuals projects will also be available as an option for students who are staying overseas or in quarantine. All project proposal and presentation sessions will be held on Zoom for Q&A purposes. Students were then required to submit a narrated short video that includes the completed work and explains the design principle of their developed vehicle system. As the teaching team cannot assess students' work as usual, extra instructions were given to each group, such as putting a stopwatch next to their product in demonstrating the functionality of their derived vehicle system. Written material such as the report can be developed and submitted as usual.

C. Student's Perception on the Course Redesign

The transition was found to be smooth as it was supported by existing e-Learning and flipped classroom approaches. Most of the teaching and learning items, such as instructional videos and demonstrations sessions have been previously transformed into flipped mode which facilitates distant learning. Meanwhile, students were found to be comfortable with multimedia forms of learning materials and equipped with some extra skills such as video production and presentation skills, which can be applied to other disciplines.

VII. CONCLUSION

The team has designed a cross-disciplinary autonomous vehicle system design course. Learning design practices guided by the First Principles of Instruction Framework have been used for developing and implementing the course. Survey responses reveal that students perceived that they achieved the learning outcomes that were congruent with the FPI. Analysis of student reflection shows that the teaching and learning activities were also effectively aligned with the corollaries of the FPI. Through analyzing student works in this course, the course team noticed that a more mature revision and execution schedule should be formed for better delivery of instructions. The course has a resilient design as it had been quickly transformed in the second cohort for online delivery.

In designing a cross-disciplinary integrative design course in the future, in addition to the design flow suggested in Section IV, we concluded that the teaching team should revise the instructions after conducting two learning activities during the progression of the course, based on class observation results and informative feedback from learners.

There are several limitations in the current research study:

- The course was offered for the first time. Therefore, further comparison and analysis are needed to yield more factors that promote effective learning other than adopting FPI principles.
- Laboratory work and project demonstration are graded mainly based on the instructor's experience. This grading mechanism resembles the way of grading students with a degree of inevitable subjectivity.
- A limited sample of students participated in the survey. Therefore, findings may not give a full picture of how students perceived the course and the learning design.

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