33rd Annual Conference of the Australasian Association for Engineering Education (AAEE 2022)
4 - 7 December 2022 – Sydney, NSW
WESTERN SYDNEY UNIVERSITY

Hybrid Mode Implementation of Engineering Laboratory Education in Digital Communication Systems

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ABSTRACT

CONTEXT

The COVID-19 Pandemic has shaped the delivery of engineering laboratory exercises. As in the authors' engineering school, Digital Communication Systems is a senior-year unit enrolling both postgraduates (ELEC9515) and senior undergraduates (ELEC4505). Since 2021, the lab classes have been conducted in a hybrid mode, with both on-campus and remote-learning students. Its laboratories consist of four two-hour instructional labs and one hands-on design project.

PURPOSE OR GOAL

This paper presents the design and implementation of a hybrid laboratory program in ELEC4505/9515 Digital Communication Systems through remote labs and virtual collaborations among students. Based on the 2021 experience, the authors evaluate and reflect on the new mode of laboratory education from both students' and teachers' perspectives. The goal is to derive practical knowledge from teaching and learning, which redefines lab activities in the post-Covid learning environment.

APPROACH OR METHODOLOGY/METHODS

To meet the challenges of learning during COVID-19, the authors designed new laboratory exercises for Digital Communication Systems in 2021, introducing remote labs and promoting virtual collaborations. The hardware-software enabling technologies adopted in the laboratories include remote control (via Zoom), software-defined radio, SPARKPlus assessment tool and MathWorks' Simulink. Student survey and performance data throughout the Semester were carefully analysed to evaluate and steer the direction of new hybrid laboratory education.

ACTUAL OR ANTICIPATED OUTCOMES

The hybrid laboratory exercises in Digital Communication Systems were successfully conducted in 2021. Besides, desirable practical learning outcomes were realised with remote labs and virtual collaborations. Furthermore, the hybrid lab program results in a satisfactory learning experience for both on-campus and remote student cohorts, evidenced by high Unit of Study Survey (USS) scores.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

As higher education in a hybrid mode has become the Norm in the post-Covid era, educators need to redesign instructional laboratory exercises to align with the new learning environment. This paper serves as a starting point for the Engineering community to discuss remote labs and virtual collaboration enabled by digital technologies. The authors believe that this arrangement resembles the future digital workplace and collaboration.

KEYWORDS

Hybrid Laboratory, Virtual Collaboration, Digital Communication Systems, and Post-Covid Learning Environment

Introduction

Since 2020, the Higher Education sector has been dramatically impacted by Covid-19. As a last resort, many institutions in Australia have no choice but to move classes to online delivery (emergency learning situation). This includes the authors' engineering school. Some disciplines might be relatively straightforward to be converted to an online mode. However, engineering education involves laboratory/physical activities that are centred on acquiring practical skills and demonstrating physical systems. They have traditionally been carried out entirely within physical laboratory settings. On a positive note, the authors have observed many teaching innovations in engineering education over the past two years. For example, Chan (2022) developed MATLAB apps with a graphical user interface to convert physical classroom-based teaching in Mechanics Engineering to online virtual simulations. Jiang, et al. (2022) created H5P interactive video to replace traditional videos, enabling remote learning students to learn better. Cuskelly, et al. (2022) engaged a large cohort of students using Discord over Blackboard and YouTube over Zoom.

As in the authors' engineering school, Digital Communication Systems is a senior-year unit of study enrolling both postgraduates and senior undergraduates. The course teaches key components of a digital communication system and current technology. Its learning outcome includes:

- LO1. describe the concepts and techniques in the design of digital communications systems to the extent of the material presented in the course.
- LO2. conduct lab experiments applying knowledge and principles and ensuring quality control in taking measurements to understand the influence of various factors on digital communications.
- LO3. demonstrate an understanding of modern modulation and equalisation techniques.
- LO4. demonstrate an understanding of coding concepts, including both source and channel coding.
- LO5. recognise the limits of existing information and undertake knowledge development by drawing upon a range of sources and media formats to synthesise the information most relevant.
- LO6. demonstrate proficiency in scoring system design tradeoff issues, by using the various principles, techniques and materials as the drivers for particular case assessment.

In 2021, lectures were delivered on Zoom (the transition might be regarded as seamless), while the lab classes (which was regarded as a huge challenge) were conducted in a hybrid model that simultaneously delivers engineering laboratory programs to on-campus enrollments and remote-learning enrollments. As for the learning contents, the lab activities have been redeveloped based on model-based design simulation and remote-accessed software-defined radio platforms for students to acquire desirable learning outcomes no matter the students' locations (on-campus or at home). As for the use of education technologies, the authors have deployed several e-learning tools to engage students throughout the Semester. In this paper, the authors describe the detailed implementation, case study and evaluation of the course they taught during the Covid (e.g. 2021). Although University intends to move all units of study back to on-campus in 2023, the authors believe this course may continue in its current form, leading to a Hyflex learning experience for the students. This may be considered the "positive" impact that Covid-19 brought into Higher Education (Engineering), as many educational innovations have been accelerated.

Core Principles Leading to new Hybrid Labs

Facing the challenge of teaching during Covid-19, the authors have reached the belief of the following core principles in Engineering Laboratory Education: i.e. learning outcomes could be achieved with either Hands-on, Simulation, or Remote laboratories if appropriately designed in an appropriate disciplinary context, which led to implementing the Hybrid Learning Environment in Digital Communication Systems. It was informed by literature. Froyd, Wankat and Smith (2012) reviewed five major shifts impacting engineering education over 100 years. Notably, the most recent shift involves computational technologies. They found that simulations, as an active learning method, had become ubiquitous in both engineering practice and education (Froyd, Wankat, & Smith, 2012). Ma and Nickerson (2006) investigated 60 full-text journal articles involving three modes of labs (hands-on, simulation, or remote laboratories). They reported that each of the three laboratory modes could deliver similar learning outcomes, as computer technologies had blurred the boundaries (Ma & Nickerson, 2006). In the authors' opinion, the laboratories in electrical engineering have three broad categories: i.e. component-level experiments, board-level experiments and system-level experiments. In most cases, system-level experiments are highly computerised nowadays, which can be effectively delivered either in physical or remote labs. The authors' implementation of hybrid labs in digital communication systems (i.e. system-level experiments) can be summarised as follows.

- As for the laboratories concerning Simulation parts, the classes could be conducted separately as UniConnect Cloud (software server implemented on AWS by the University) to host all licensed software (such as standard engineering software: MATLAB/Simulink and ANSYS) required in the labs (UniConnect, 2021). Therefore, students could access them on a seven-day twenty-four-hour basis.
- As for the laboratories concerning Physical hardware parts, the authors have adapted the platform (Analog Device Software-Defined-Radio), which had an in-built interface that computers could control. It means that as long as the remote students have access to the lab computers and the staff is able to supply a camera, the remote learning students could carry out experiments just like they would if they were on campus using the computers as their "hands" and the cameras as their "eyes." Therefore, the authors equipped each workbench with a camera and made on-campus computers accessible to online students using Zoom Remote Control (therefore instruments). Another difficulty was that certain devices still required manual changes throughout the courses. Therefore, the authors began pairing online and on-campus students to collaborate on the lab tasks. The authors believe that this arrangement resembles the future digital workplace or collaboration.
- The setup of the hybrid digital communications lab is illustrated in Figure 1.

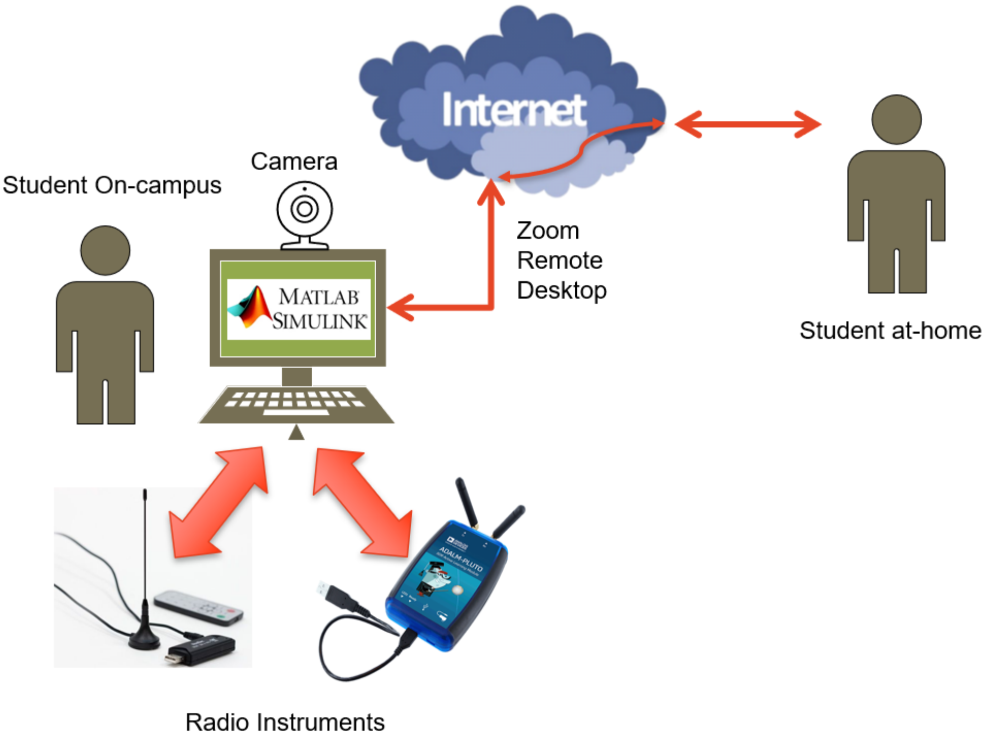

Figure 1. Hybrid Digital Communication Lab (Hardware) Setup Overview.

Design and Teach Hybrid Instructional Labs and Projects

Digital Communication Systems have a substantial design element requiring students to model, simulate and design a prototype of a digital communication system. In 2021, its practical program was revamped to enable hybrid laboratories and collaboration based on a software-defined radio (SDR) platform. The learning activities within the laboratories and projects were broadly based on Fading Scaffolds for Active Learning (Lin. etc., 2011). The authors organised students into groups with mixed on-campus and remote-learning students. The lab classes had four instructional lab sessions and one take-home project (home-lab) consisting of five progressive milestones.

- As for four **synchronous** lab sessions, students met on Campus or joined in remotely via Zoom in timetabled two-hour slots. Hardware (enabled by remote access) was set up on-campus, allowing collaboration between on-campus and remote-learning students. Two tutors and one lab instructor delivered the laboratories by starting with a class demonstration. Then students worked collaboratively on the hands-on tasks while the authors supervised and provided feedback.
- For the **asynchronous** project component (i.e. a home lab) that spans the entire Semester, the authors gave on-campus students all the electronics by Week 3. They worked with remote-learning partners at their own pace and place (unsupervised) to design an advanced digital communication system over the Semester. The collaboration resembles synchronous lab sessions by allowing remote control of the hardware among students. Meantime, the authors provided fortnightly consultations to advise on the project. It was an entirely student-led activity, and students completed this design project using knowledge gained from lab sessions and their own research.

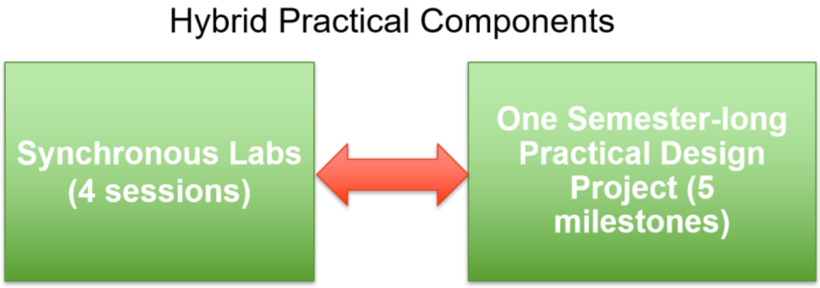

Figure 2. Practical Laboratories.

The synchronous labs and asynchronous project components are worth 15% and 25% of the course's overall assessment, respectively. They are complementary to the lectures covering digital communications theories. The aim of the synchronous labs and the asynchronous project is to develop a communication system that is designed and demonstrates over-the-air operation using the SDR platform. The topics covered in the synchronous labs are organised into four sessions, as follows:

1. Lab 1 Model-Based Design using Simulink
2. Lab 2 Software Defined Radios and their Architectures
3. Lab 3 Quadrature Modulation and Demodulation
4. Lab 4 Digital Signal Processing in Digital Communication Systems

The four synchronous lab sessions support the semester-long project by teaching essential skills in developing communication systems using the SDR platforms. The project aims to cover topics including error control coding, modulation, demodulation, pulse shaping and synchronisation. Conceptual building blocks for digital communication systems are illustrated in Figure 3, which consist of source coding, channel coding and digital modulation. In practice, complex baseband processing and RF operations such as up-conversion, down-conversion, carrier and synchronisation recovery, and phase offset are also necessary. In the project, students would design and implement a practical digital transceiver system that includes conceptual and RF signal processing blocks. The list of project topics can be found as follows:

1. Set up software and hardware
2. Getting familiar with the technical computing environment
3. Getting started with RTL Software Defined Radio with MATLAB/Simulink
4. Digital modulation and pulse shaping
5. Digital up- and down-conversion
6. Baseband simulation model
7. Frequency synchronisation
8. Carrier synchronisation
9. Timing errors and symbol recovery
10. Data and frame synchronisation
11. Complete communication model
12. Getting started with ADALM-PLUTO with MATLAB/Simulink
13. Demonstrate software-defined receiver–message transmission
14. Demonstrate software-defined receiver–image transmission
15. Final project report

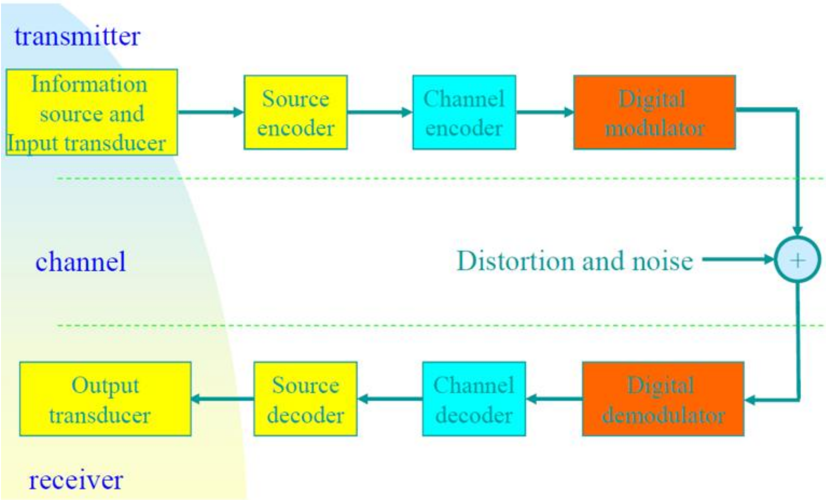

Figure 3. Digital Communication Systems Block Diagrams.

The project is worth 25% of the final mark and comprises 5 phases, as illustrated in the table below. Students worked in a group of 3 students, mixing on-campus and remote-learning students.

Table 1 Project Phases

Phase	Activities	Milestones Due	Assessment
1 Initial stage	Topics 1, 2, 3	Week6 Monday	3%
2 Preliminary Design	Topics 4, 5, 6	Week8 Monday	6%
3 Detailed Design	Topics 7, 8, 9, 10, 11	Week 12 Monday	8%
4 Demonstration	Topics 12, 13, 14	Week 13 Monday	5%
5 Close Stage	Topic 15	Week 14 Monday	3%

Assessment and Feedback

In 2021, ELEC4505/9515 had its practical laboratories and project components accounting for 80% of in-semester assessments (or 40% of the total assessment, including the final exam). As for timetabled instructional labs, the authors assessed four in-lab demonstrations (on Weeks 3, 6, 8, and 10) and three post-lab technical reports. As for the off-campus design project, the assessments included five milestone demonstrations (on Weeks 6, 8, 12, 13, and 14) and their corresponding milestone reports, as shown in Table 1.

In 2021, lab assessments were set for improvement of learning (Ashwin et al., 2020), guided by University's Assessment Procedures 2011. Learners can receive feedback from teachers and students with a multi-faceted approach either in-person (for on-campus students) or Zoom (for remote-learning students).

- First, within most of a two-hour synchronous lab session, a group of three students worked on tasks at one electronics workbench, and the tutors and instructors came to each bench for discussion, Q&A and demonstration. Therefore feedback and feedforward processes could co-occur interactively.
- Second, in 2021 the authors wrote detailed marking rubrics for each assessable lab and project milestone. This was improved from checklist-based criteria in the previous years. The new eight rubrics (three for labs and five for the project milestones) were standard-based criteria that communicate expectations for High Distinction (HD), Distinction (D), Credit, etc., showing achievable steps to realise them.
- Third, the assessment includes a demonstration assessed on the spot and a technical report submitted later to Canvas. Students received immediate feedback from the Staff on their practical demonstration in class. The Staff also marked written reports on Canvas within two weeks, providing our reasons according to rubrics and commenting on future improvements. The report process was done entirely on the Canvas platform.
- Forth, the lab and project assessment was group-based as the authors intended to promote collaboration. When working in groups, students could receive feedback from each other. However, some students reported the "free-rider" issues to us, which was an undesirable outcome of our team-based assessment. In 2021, the authors used SparkPlus to have a formal peer-review process that encouraged fair contributions and adjusted marks accordingly. Willey and Gardner (2010) reported studies that SparkPlus engaged students and supported them to learn in Engineering.
- Fifth, the authors held fortnightly consultations to advise on labs and projects. During the time, the conversation with students was informal and relaxed. The authors recalled during one conversation; one remote-learning student talked straight for five minutes about how difficult he was doing remotely. The authors acknowledged his feelings and assured him that remote labs in this course would be as practical as the physical labs. As for communications, the authors also send students personalised emails on a regular basis using the Student Relationship Engagement System (SRES, 2021).

Overall, engineering laboratories expect students to have difficulty and require considerable effort, which is one of the objectives in laboratories (Feisel & Rosa 2005). Laboratory assessments in this course were spread out the entire Semester, and the difficulty level of their tasks was gradually increased. The authors aligned a multi-faceted feedback/assessment approach to "assessment for improving student learning" (Ashwin et al., 2020). Students had many occasions (formal and informal) to receive feedback from teachers and peers to improve their work.

Outcomes and Discussion

At the end of each Semester, students are invited to provide feedback on a unit of study via the Unit of Study Survey (USS). USS is a foundation for improving the student learning experience at the University, and it is the formal university-wide process to evaluate the quality of education from students' perspectives. USS collects both quantitative and qualitative data, and quantitative data is typically converted to a rating indicator for comparison. In 2021, there were 12 quantitative (multiple choice) and two qualitative (open-ended) survey questions. Below were the 12 multiple choice questions, and there were five answers to select (Strongly Agree, Agree, Neutral Disagree and Strongly Disagree), mapping to a rating of 5, 4, 3, 2, and 1, respectively.

- Q1 Overall, I was satisfied with the quality of teaching by the teacher(s).
- Q2 The work has been intellectually rewarding.
- Q3 I developed relevant critical and analytical thinking skills.
- Q4 I have had good access to valuable learning resources.
- Q5 The assessment tasks challenged me to learn.
- Q6 I have been guided by helpful feedback on my learning.
- Q7 I have felt supported to learn in the online environment.
- Q8 I felt part of a learning community.
- Q9 I developed my ability to think independently about problems.
- Q10 I developed my ability to work effectively with digital and online tools and information.
- Q11 I developed my capacity to respond constructively to challenge.
- Q12 I developed the ability to practically apply knowledge of the field(s) I am studying.

Some colleagues may argue that such a USS study may not accurately indicate quality education across different courses from different disciplines. However, the authors believe it is a relatively good indicator for those units in the same field, particularly the same class, across several years. In this paper, therefore, the authors primarily use USS data as the benchmark to evaluate the education in the Digital Communication Systems course over the four-year period.

Digital Communication Systems is a senior-year unit enrolling both postgraduates (ELEC9515) and senior undergraduates (ELEC4505). ELEC9515 cohorts have comprised primarily international students. Over the four-year period, the average enrolment number of ELEC4505 is 22, and that of ELEC9515 is 15. USS is voluntary and anonymous as individual identifying information was not captured. Table 2 shows students' participation rate (responding to the Survey) from 2018 to 2021. 2018 and 2019 were two years (before Covid) considered traditional teaching and learning. 2020 was the year that Covid hit Australian Higher Education surprisingly, and 2021 was when the authors implemented the new Hybrid Labs described in this paper.

Table 2: USS Participation Rate.

	2018	**2019**	**2020**	**2021**
ELEC4505	42%	29%	41%	35%
ELEC9515	72%	93%	45%	67%

Table 3 and Table 4 show USS Q1-6 average and Q1-12 average (descriptive statistics). As shown in the two Tables, two indicators are highly correlated. The authors observe that the ELEC9515 cohort reported the worst learning experience (3.53 in Q1-6 mean or 3.48 in Q1-12 mean) in 2020. It could be explained as follows. ELEC9515 primarily consisted of overseas students impacted by Covid travel restrictions, who most likely studied remotely. In 2020, the authors converted traditional labs into video recordings as replacement lab activities. However, these initiatives did not address students' needs for active participation in the course's practical components. Therefore, in 2021, the authors completely revised the class's practical components (labs and projects) and improved assessment/feedback processes to address the gap observed in 2020. The USS results in 2021 were very encouraging, and the authors observed that the students' experience was considerably lifted from 2020, and they scored even better than those in pre-covid years.

Table 3: USS Q1-6 Mean.

	2018	**2019**	**2020**	**2021**
ELEC4505	4.04	3.92	4.24	4.35
ELEC9515	4.41	4.32	3.53	4.72

Table 4: USS Q1-12 Mean.

	2018	2019	2020	2021
ELEC4505	4.08	3.95	4.15	4.4
ELEC9515	4.4	4.37	3.48	4.69

Besides, the authors also compare the USS scores against the school average. Specifically, in 2021, the Q1-Q6 mean of ELEC9515 USS was 4.72, and that of ELEC4505 was 4.35, both of which exceeded the school average of 4.15. As for the question "Q12 I developed the ability to practically apply knowledge of the field(s) I am studying", both Units scored 4.67 on average. Furthermore, students perceived that the assessment tasks challenged them to learn (USS-Q5 scores of 4.67 in both ELEC4505 and ELEC9515), while the school USS-Q5 average was 4.24. And students also felt guided by helpful feedback by reporting USS-Q6 scores of 4.11 in ELEC4505 and 4.67 in ELEC9515. In reference, the school USS-Q6 average was 4.02. In addition, ELEC4505 and ELEC9515 USS Q1-Q6 means were well above the school average.

As for overall practical assessments between on-campus (OC) and remote-learning (RL) students, in 2021, the mean of on-campus students scored 34.96 for overall practical assessment (out of 40), while that of the remote learning students had 33.97. On average, students enrolled in on-campus and remote learning have similar performance. In 2021, there is little difference between the two groups of students in terms of learning outcomes under the hybrid model.

Conclusion and Recommendations

Higher education in hybrid mode has become the Norm in the post-Covid era. To deliver learning outcomes to the new generation, educators must redesign instructional laboratory exercises to serve the unique learning environment best. In this paper, the authors describe its detailed implementation, case study and evaluation of the Digital Communication Systems course that they taught. The lab activities were redeveloped based on model-based design simulation and remote-accessed hardware platforms for students to participate in the practical exercises wherever the students were located (on-shore or overseas). Besides, the authors have deployed several e-learning tools to engage students, such as SparkPlus (to improve peer and self-feedback process) and SRES to provide personalised communications.

At the time of this writing, the authors analyse the USS data over a four-year period from 2018 to 2021 and observe that the student's perception of education quality in 2021 was considerably lifted up from the 2020 low. According to the descriptive statistics, they were rated even better than those in pre-covid years. In addition, on average, students between on-campus and remote learning scored practical assessments closely enough to see the difference.

Although the University plans to move all units of study back to the single on-campus mode in 2023, the authors intend to keep this course in its current form (hybrid mode). The authors hope that this practice can serve as a starting point for the Engineering community to discuss HyFlex learning in Engineering and believe this arrangement resembles the future digital workplace and knowledge collaboration.

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Acknowledgements

The authors gratefully acknowledge two tutors: Likun Sui and Jichao Leng, and both on-campus and remote-learning students for teaching and learning in the hybrid mode.

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