

Remote Practicals in the Time of Coronavirus, a Multidisciplinary Approach.

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Abstract

Due to the COVID-19 pandemic, universities across the world have curtailed face to face teaching. Associated with this is the halt to the delivery of the practical experience required of engineering students. The Multidisciplinary Engineering Education (MEE) team at The University of Sheffield have responded to this in an efficient and effective way by recording the laboratory experiences and putting videos, quizzes and data online for students to engage with. The focus being on ensuring Learning Outcomes for modules and courses have been preserved. Naturally, practical skills cannot be easily provided using this approach, but it is an effective way of getting students to interact with real data, uncertainty and equipment which they cannot access directly .

A number of short case studies from across the range of engineering are provided to inspire and guide other educators in how they can move experiments on line in an efficient and effective manner.

No student feedback is available at the time of writing, but anecdotal evidence is that this approach is at least acceptable for students and a way of collecting this is suggested. The effort that has gone into this approach and the artefacts produced will support student learning after the initial disruption of the lockdown has passed.

Introduction

With lockdowns implemented globally, and face to face teaching stopped, the way that most universities teach has been disrupted. Technology can effectively replace many forms of classroom experience. Flipped and blended learning modes are well established in the teaching pantheon and Zoom, Google Meet and Microsoft Teams allow reasonably effective face to face teaching to take place in terms of live lectures and tutorials. The development of Virtual Learning Environments (VLEs) such as Canvas, Blackboard and Moodle allow the provision of teaching material and assessment to take place. However, in engineering and the sciences there is the need for students also to conduct practical work. Sometimes this requires specialist, large equipment or riskier activities. The rest of this paper discusses and gives

examples of various innovative ways of moving practical activities away from face to face to a virtual delivery.

Multidisciplinary Engineering Education (MEE) is a specialist department at the University of Sheffield which is dedicated to delivering practical teaching for all of the students in the Faculty of Engineering using large, shared laboratories and workshops. These are clustered around themes, and students from the 10 major courses in engineering do their practical learning in this environment. MEE consists of a staff of around 50, including 30 teaching technicians and 15 academic staff, each of who is responsible for delivering an area of practical learning to students across the entire faculty. In addition to this, MEE employs more than 200 PhD students as graduate teaching assistants (GTAs) each year, in order to support learning, supervise students and assist in marking laboratory assignments. Due to the ubiquity of some basics of engineering, some of the activities in this area are provided to 1000 students a year from 7 different courses. This economy of scale and concentration of practical teaching expertise has made for an excellent student experience. The scale of the operation has also required a large infrastructure and there are 5 administrators to lead on ensuring that the timetable, marks, lab books and the student experience are all supported.

From MEE's inception in 2015 we have worked with departments in the Faculty of Engineering to integrate the practical teaching seamlessly into their courses, usually delivering practical learning to the entire cohort as subjects are introduced by the lecturer. We are generally able to deliver an identical experimental activity to a cohort of up to 320 students in only a few sessions in the same week because of the scale of our laboratories. Our 5 largest laboratories can accommodate between 80 and 144 (Electronics and Control Lab) students to teach the same activity at once.

MEE is dedicated to the delivery of practical teaching and as a result we carefully consider how to ensure our teaching is as effective as possible¹. Since opening in 2015 we have adopted a blended learning approach for all our experiments; the "Lab Sandwich". Figure 1 shows all 5 steps in the design and implementation of virtual labs, of which the central 3 elements are core to all of our practical activities:

1. **The pre lab.** This element is delivered online using the VLE and prepares the student for the experiment. As a minimum, it contains the theory and the learning outcomes, information and often videos on the equipment and its use, and the Health and Safety precautions. The pre lab will also contain quizzes to ensure that the students have read and understood the content. As this is universal across all of our laboratories, we are able to employ a consistent policy of refusing entry to students who have not completed the pre lab requisites.
2. **The lab.** Here students actually do the practical work. Due to our ability to take a panoptic approach to student learning, the time spent in the lab is optimised as the preparation and an understanding of the theory behind it and

what they are required to do has been provided in the pre lab. This saving of valuable laboratory time has allowed us to integrate more experiments into our courses, so students experience a larger variety of activities.

3. **The post lab.** This is to ensure that students have engaged with the exercise and are able to reflect on it. It could be a quiz, a report or a piece of work integrating ideas across a number of experiments. Often there is no need to assess the lab summatively, as it is integrated into and thus tested in the associated course assessments.



Figure 1: Process of virtual labs

Our basic approach to moving the labs to an online delivery has been to increase the size of the pre lab so that it also incorporates the lab itself. It is appreciated that this will not be able to replace all of the experience, but as a way of supporting departmental teaching and the curriculum, it appears to be an effective device and gets students to think about data, theory and validation. We do not at present have much scope for delivering true remote experiments where students control the equipment from home, but these could easily be incorporated into the general framework described here.

Literature review

When moving practical teaching from face to face to remote teaching, three main approaches can be taken: simulation, remote control of equipment and data acquisition, and providing recordings of data and experiments. A couple of thought papers by a consortium has sought to contextualise this, but they have not yet implemented any form of teaching^{2,3}.

One of two early (2007) papers on remote laboratories explicitly describes three types of laboratory⁴.

- (a) Development Lab, where students answer specific questions about the design and determine if a design performs as intended.
- (b) Research Lab, generally an addition to the body of knowledge.
- (c) Educational Lab, where students apply theoretical knowledge to gain practical experience.

They also refer to the value of pre lab experiences and acknowledge that the remote lab at that time could not replace all of the experience of a face to face laboratory.

The other (2006) early work on non face to face laboratories is a literature review on the subject of “Hands-On, Simulated, and Remote Laboratories”⁵. They state that for many remote laboratories, the more effective the computer interface is, the easier the lab is to move online.

An exciting piece of work uses remote controlled and internet enabled experiments to allow students to engage with real equipment and data while at a different location⁶. This approach has two advantages in that one set of equipment can serve many students and that the results are those from the real equipment with noise and nonlinearities. A large scale piece of work on remote and virtual laboratories has been conducted in Germany on manufacturing and materials testing⁷. Not surprisingly, they label this “Education 4.0” and it has increased student understanding and engagement, particularly for MOOCs. They report that students who have conducted the remote practicals arrive for real laboratories far more prepared, much like MEE’s pre labs.

A group from Mexico and the UK have created a series of remote mechatronics and electrical laboratories, which can be controlled and data acquired remotely using LabView software and a webserver to allow users to interface with them⁸. They have reported on three laboratories: an electropneumatic system, control of AC motors and residential wiring circuits. Their student feedback has been small, but they report that students like the interface and can follow the experiments while lectures are being conducted.

A publication that looks at the effect remote experiments on student learning makes a few interesting comments⁹. Firstly that remote experiments work better for earlier years, and secondly that effective remote experiments are an integration of three elements “The first was technical/technological, the second was administrative and the third academic.” This shows that there is more to putting on effective laboratories (both conventional and remote) than merely moving them on line. Their work also implies that remote experiments with good staff support are a useful element for inclusion and a variety of learning styles.

A report on the Australian Labshare Project¹⁰ looked at the student experience of a series of remote electronics and control laboratories shared between 6 universities. Their results show that students actually preferred the remote laboratories except for “Help and support if required”. As can be seen from other investigations, they report that staff support and engagement are key to student success. They also state that it may be required to have different Learning Objectives (LOs) than for conventional experiments. Another of their findings is that students do better on subsequent remote experiments than on their first one, so there is an induction process to be undergone for this type of lab too.

Most of the work that has been found in the literature refers to electronics and control laboratories, but a consortium of universities has built a remote materials specimen testing lab which can be used by both staff and students¹¹. They have not yet used the system with students, but it looks powerful and effective.

Another approach that can be taken is using common equipment in the form of a “take home lab”¹². Here students use artifacts around them to engage with measurement and analysis. This can be a powerful aid to augmenting traditional teaching, but could have elements of risk unless students are carefully inducted.

From these previous examples, it can be seen that remote laboratories are becoming more prevalent. However, they require a lot of time and effort to implement effectively. Additionally, most of the topics approached are, not surprisingly, from the electronics and control fields where computer interfaces are ubiquitous. In the time when conventional laboratories are suddenly not available, a quick fix without additional hardware modification is necessary. The work described below from The Department of MEE at the University of Sheffield provides a large number of multidisciplinary approaches to moving the practical experience on line in a fast and efficient manner. These aim to preserve as much as possible of the student experience as far as possible.

General approach

At the University of Sheffield, the Faculty of Engineering teaches 4700 undergraduate and taught postgraduate students across 10 degree programmes. The MEE department is responsible for delivering over 2000 individual practical activity sessions comprising 600 different experiments to these students. Both the scale of the operation and the complexity of the service provision model requires effective infrastructure and robust communication channels to effectively function. This infrastructure includes:

- Appointed academic liaison staff to act as a point of contact and provide overarching management of sessions for each degree programme.
- A master spreadsheet, known as the Directory of Activities (DoA), which uniquely identifies and records metadata associated with all of our activities, such as the staff member responsible for each activity and the staff member responsible for the module in which the activity sits.
- A departmental timetable of all practical activities, linked to the DoA using unique identifiers, administered by a learning and teaching manager.

This infrastructure made it easier to create a rigorous process to pivot to remote delivery. This was developed and agreed within 24 hours of requiring to change our delivery method by the MEE executive group. A spreadsheet was produced from the timetable with a list of the 602 practicals still to be taught in 14 different laboratories. Through linking this spreadsheet to the DoA, metadata for each session was attached, including the MEE staff member responsible for delivering the practical session and the module lead responsible for the entire teaching of the module, including lectures, tutorials and assessment. Each member of staff responsible for an activity would be tasked with finding the most appropriate teaching method to deliver their practicals remotely, and asked to populate the spreadsheet with information about what was done and what impact this would have on assessment.

Having a single location for all this information allowed:

- Effective communication with the Faculty level Learning and Teaching Committee, who report to the central University learning and teaching committee. The information about the impact on assessment was particularly important to form the University's policy on concessions for students due to the disruption.
- Effective liaison between departmental directors of learning and teaching, module leaders and module teaching staff, who may have wanted to know the process we adopted for our teaching delivery, or to respond to their student's enquiries.
- MEE departmental management staff to audit completion of the move to remote practical and departmental administrative staff to respond to student emails without the need to involve academic staff.

As soon as the suspension of face to face teaching was announced, the Head of MEE called a meeting to get staff to discuss and develop strategies to move forward.

During this meeting the process for recording methods to move teaching online was disseminated. As practical work is fully integrated into most Sheffield engineering courses and forms a key to students understanding and contextualising material, it was inadvisable to just remove the experiments from the courses. It was therefore decided that as a general approach we would replace the conventional lab sessions with an online delivery of the lab and use videos, data and quizzes to get the students to engage with the existing learning outcomes. Due to our experience on creating pre lab activities, this was a relatively small intellectual step, but in many cases required a huge amount of work to prepare and deliver. A number of other approaches were considered, such as abandoning the experiments, getting students to do this work at home, running experiments from students' locations and just providing data for the students to process. Understanding that our response was reactive, we wanted to reproduce as much of the experience as possible within a very short timeframe.

By virtue of our pre labs, students were already prepared for online learning as part of their lab experience. This made it easier for us to engage them and for them to know what expectation we had of them.

Typically for the UK, at the University of Sheffield, there was a window of a week or so between face to face teaching being curtailed and full lockdown of the campus commencing. MEE were able to use this time to prepare for working at home to deliver remote practicals. This short amount of time when we still had access to the building was used to get organised and record films and data. The teaching technicians were fully engaged in this process and their expertise allowed an enormous amount of recording of practical work to be carried out.

Staff had about six weeks to then edit these videos, prepare online quizzes and experimental data, and adapt their assessments for each activity. This also entailed discussing and negotiating with the module leaders in departments from across the faculty what experience their students were going to have in lieu of the timetabled practical sessions.

What follows is a series of short case studies covering a wide variety of engineering subjects and approaches taken to mitigate the issues around the sudden curtailing of laboratories. We hope that these will inspire others to be able to continue to provide students with a reasonable practical experience when university laboratories cannot be accessed. We have chosen to present a small subset of all our case studies (CSs) below, which we believe best demonstrates the flexibility and diversity of delivery methods that can be implemented effectively across engineering fields even on short timescales. However, many more teaching activities had to be adapted for online delivery, hence an even larger number of other CSs is presented in the Appendix. The highlights include:

- video demonstration of cement making (CS10)

- training video on the use of SEM and performing energy dispersive X-ray analysis (CS11) of materials that can be used to train project students in the future
- Videos of a series of experiments on biopharmaceutical engineering (CS12) were created to allow students to engage with the “normal” assessment regime
- students recording data from videos of technical staff measuring optical density in bioreactor engineering (CS13)
- students assessing the accuracy of two techniques used to measure water contact angles (CS14) based on a video demonstration
- video conference with staff and students organised to retain a sense of community and answer any arising questions (CS15)
- data analysis and reflection using provided data to create Mohr’s circles for a hole-in plate (CS16)
- investigating differences between theory and physical systems by presenting a cut-away model of a jet engine demonstrating positions of various sensors from which data is collected (CS17)
- students recording data from high-resolutions photographs of refraction and reflection measurements and calculating refractive index of materials from it (CS18)
- providing students with a calculation validation tool to ensure correct methods were used before students plot results and submit their work for assessment (CS19)
- continuing extra-curricular electronics skills development via a website full of practical project ideas that can be undertaken both physically and through open-source software (CS20).

Table 1 summarises all of the case studies presented in this paper, with those in the Appendix marked with an asterisk (*) and located towards the bottom of the table. It indicates which delivery methods were utilized in teaching each practical subject.

Table 1: The case studies in this paper and its appendix.

	Video of the experiment	Video instruction	Experiment performed at home	Data analysis	Simulation	Quiz	Student - staff interaction
1 Magnetic materials	X	X		X			
2 Protein	X	X		X		X	

separation and validation							
3 Pilot plant experiments					X		X
4 Flow in pipes and valves		X	X	X		X	X
5 Heat exchangers		X		X		X	
6 Design, manufacture and test of LEDs	X						X
7 Circuit design					X	X	
8 Control and instrumentation	X			X	X	X	
9 Robotics					X		X
*10 Cement making	X			X			
*11 SEM instruction		X					
*12 Biopharmaceutical Engineering	X						
*13 Bioreactor Engineering	X			X		X	
*14 Fabricating a superhydrophobic surface	X			X		X	
*15 Frictional losses in pipes				X		X	X
*16 Mohr Circles for a hole-in plate				X			X
*17 Jet engines and the Brayton cycle	X			X		X	
*18 Optics	x	x		x		x	

*19 Electrical machines and drives	X	X		X		X	
*20 Extra-curricular electronics		X	X		X	X	X

A series of case studies on remote practicals from MEE at the University of Sheffield

1 Magnetic materials

The video developed for magnetic materials illustrates the setup for measuring the response of two different magnetic materials (soft and hard) under a changing external magnetic field by collecting data across a range of field strengths generated by an applied voltage.

A teaching technician created a recorded walkthrough on the data analysis using excel. The students were required to draw a hysteresis loop from the supplied data collected, by integrating and normalising the values of magnetisation from the electrical signal. This was a section of the practical where the students typically struggled, so effort was placed into supporting student learning enhancing their learning experience and capability when normal practical teaching resumes.

2 Protein separation and validation

To explore how the function of cells and tissues can be investigated as well as practice techniques used in disease testing and diagnosis, 2nd and 3rd year bioengineering students carry out protein separation using gel electrophoresis and validate the presence of a particular protein using antibodies. With the suspension of face to face teaching an online activity was created so that students could gain an understanding of the principles of these techniques and evaluate their effectiveness and limitations. A video of gel electrophoresis was produced with the same level of detail as provided in the lab script, so that students could still calculate the concentration of protein solutions and provide answers to an online test. A series of captioned figures showing the expected data from the experiment meant students needed to analyse and interpret the data in order to answer the questions in the online test.

To demonstrate how antibodies can be used to validate the presence of a particular protein, several online resources were used and a game that is usually played during the lab session was recreated online to help students apply their knowledge and determine how antibodies are selected when designing an experiment (Figure 2). Additionally, students were asked to complete a short write-up (750 word limit)

discussing the use and limitations of the techniques in research and medicine, providing relevant examples, including an example of how antibodies are being used in the fight against COVID-19. Almost all of the cohort have engaged with the online learning activity, which under the circumstances is encouraging.

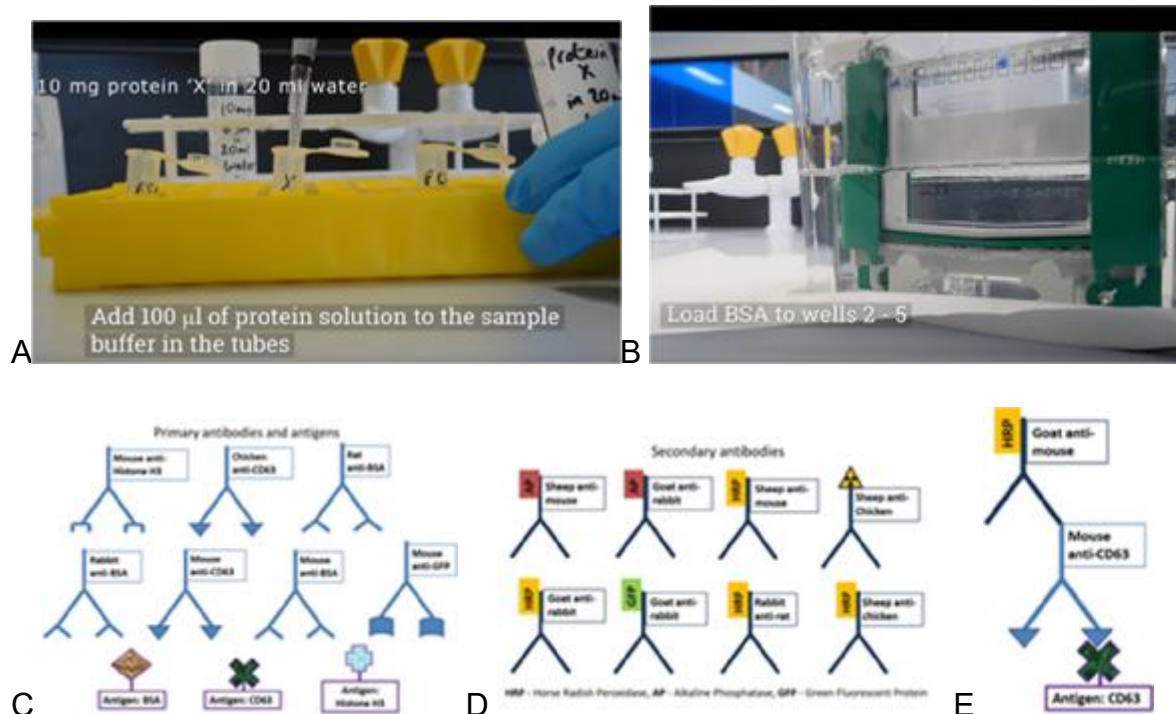


Figure 2: Images of the video showing (A) the preparation of the protein samples and (B) how they are loaded into the gel. (C & D) Images of different antibodies used in the antibody game. (E) Answer to an online test question.

3 Pilot plant experiments

The experiments which utilise the Diamond Pilot Plant (DiPP) facilities, see Figure 3, allow for more complex and open ended experiments and it was more challenging to develop an online activity. The rigs available in the DiPP are all industrial scale and permit the investigation of a number of process parameters. Students use this facility to conduct experimental investigations and collect data for further statistical analysis. One of the main LOs in these experiments is pre-planning through a Design of Experiment (DoE), which students are required to carry out utilising statistical approaches before arriving at the lab. Students were to be interviewed in the lab by a Graduate Teaching Assistant (GTA) to check on their plan and then they were to execute their DoE and collect data during the session. After the suspension of face to face teaching, assessment had to change.

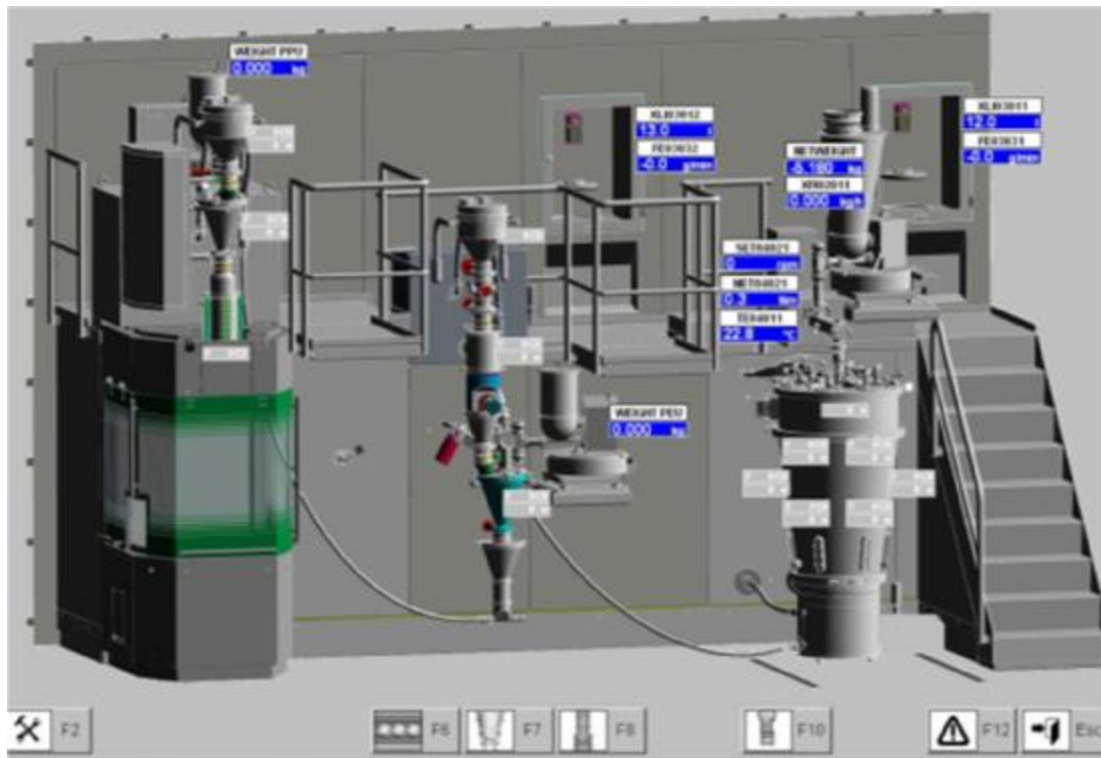


Figure 3: ConsiGma25 powder to tablet line, showing the complex unit operations with wide range of process parameters to be controlled to produce pharmaceutical tablets

Two approaches were taken. In the week between the face to face teaching suspension and the complete lockdown of university facilities students were asked to carry out their pre lab preparation and DoE as normal. However, this was submitted as online VLE assignments to substitute for the in-lab assessment. The execution of the DoE and the lab activity was then conducted by proxy, where GTAs (who were allowed in the plant) conducted the experiment and collected data for students. The second approach was implemented after the complete lockdown at which point the students were still required to submit the pre-planning as online assignments. However, the execution of the experiment was not possible at that period of time. Instead, data was extracted from a database, which had been collected previously.

These two approaches were found to be an effective replacement for the normal experiment. They were well received by the students. The other important LO of these experiments was the development of transferable skills in this case effective communication and team working. These were still achieved as students were required to do all pre-planning and post lab reports in groups and then complete a peer assessment form. The engagement and interaction with students and the progress of the work were monitored using weekly Blackboard Collaborate sessions, where the whole teaching team was available to answer questions from students.

4 Flow in pipes and valves

Two experiments on laminar/turbulent flow and flow controlled by taps were due to be carried out before the suspension of regular teaching. The assessment of the former focused on experimental record keeping, while that of the second involved submission of a short report. These two practicals were combined and adjusted to be performed by students in their own homes. Access to equipment domestically can be variable, however, most students typically have access to water from a tap and rudimentary instrumentation, such as weighing scales or measuring containers. While this equipment would be less accurate than laboratory instruments and would vary from student to student, the LOs did not depend on these factors. A new assignment brief and explanatory video (including showing the member of staff's kitchen with tips and suggestions on how to complete the lab) was created. Teaching material that formed the original pre lab activity, including videos and documents of the equipment in the laboratory, was retained for the student's reference. The marking criteria remained virtually unchanged.

In addition to providing detailed guidance to allow students to work remotely, two aspects were incorporated to facilitate this mode of delivery. Firstly, students were informed that they would need to think creatively in order to engage with this activity. As this was not an explicit LO, it did not form part of the summative assessment, but as engineers need to employ creativity regularly, this was an opportunity to practice that skill. Secondly, although the activity is intrinsically safe (running water from a tap), it is important that we exercise a duty of care while instilling the need to assess risk in changed circumstances. Students therefore completed a risk assessment before undertaking any work. All students in the faculty are trained in completing risk assessment as one of their first timetabled activities, called "the Danger lab"¹³. Any work received without a completed risk assessment would receive zero marks, which is usually a sufficient incentive for compliance.

Anecdotal feedback suggests the student enjoyed the experiences and valued the effort of staff to replicate the face to face experience remotely given the short notice and constraints.

5 Heat exchangers

The original aim of this first year mechanical engineering experiment was to apply the first law of thermodynamics to a practical application for a range of operating conditions. Within their studies students will often only investigate a single operating point whereas in an industrial setting equipment will have an operational range. Students were required to vary two parameters (hot and cold flow rates) and capture at least 15 data points. Within the lab class there was often insufficient time to analyse all the data in detail, hence a few extreme cases would be investigated instead. When the experiment could not take place, students were instead provided

with a set of example data. The entire data set was then processed by students in more detail than would have been possible within a practical class.

Processing was performed using a spreadsheet (Excel). Analysis using spreadsheets within labs has been attempted previously but largely abandoned due to the range of student skills. Generally more confident (often over confident) students take over the computer whilst others look on and the class becomes a spreadsheet tutorial rather than thermodynamics practical. A significant portion of the students have little or no spreadsheet experience and find their use alienating. With this in mind videos were created analysing part of data in Excel, this covered calculations and the creation of scatter graphs. Emphasis was placed on the professional production of charts as this is a useful skill going forward. The final online exercise consisted of 5 parts: a 14 minute introductory precoded powerpoint presentation looking at the equipment and background theory, an 11 minute video detailing data processing within Excel, a 10 minute video examining the production of scatter graphs, a 12 minute recorded powerpoint presentation reviewing the resultant figures and finally a 6 question online quiz consisting of multiple choice (4) and calculations (2) questions.

Two attempts at the quiz were permitted to encourage the students to attempt the quiz and then correct their mistakes. It was decided to keep the assessment as close as possible to what was planned for the original experiment. In future iterations the assessment would be adapted to test and encourage the use of spreadsheet processing. Furthermore, data visualisation with scatter charts revealed further depth to the data permitting more advanced concepts to be observed. In particular it was possible to draw conclusions on the impact of fluid dynamics on heat transfer. Discussion of these is a useful primer for heat transfer which the students are introduced to later in their studies. There was not time to set up any sort formal feedback from the students, however, no negative feedback (this usually being much easier to obtain) has been received on the approach of using spreadsheets to process the data. One student has provided advice on useful shortcuts to the Excel processing.

6 Design, manufacture and test of LEDs

MEE has a bespoke teaching Cleanroom. This 300 m² facility has a rating as high as ISO6 (>1000 times less dusty than a normal laboratory), enabling the manufacture and test of electronic, optoelectronic, micromechanical and microfluidic devices with features as small as 1µm.

Following the move of teaching online, two two-hour virtual lab (vLab) sessions were delivered to first year Electronic and Electrical Engineering students. These vLabs explored the technology relating to light emitting diodes (LEDs). The first vLab took the students through the basic physics of a p-n junction, followed by the

measurement of the electrical characteristics (current vs voltage) of blue and red emitting LEDs. The second vLab investigated the optical properties of the LEDs and finished with a discussion of the methodology for creation of white light by using a blue LED with a yellow phosphor.

The Cleanroom vLab experiences largely followed the standard MEE model, with pre lab and post lab activities, together with the actual vLab experience, which comprised a set of slides, supplemented by short video clips that gave the students a tour of the lab and showed recordings of the collection of the electrical and optical test data. This real data (complete with its imperfections) was shared with the students and formed the basis of their post lab analysis.

In a departure from many of the other case studies presented in this paper, the vLabs were delivered *live* via Blackboard Collaborate VLE by the university teacher. This real-time approach enabled many question and answer (Q&A) interludes to be dispersed throughout the presentations. In these Q&A sessions, the students could remain anonymous and this, hopefully, encouraged more of them to participate. They asked and responded to questions by annotating the slides (Figure 4).

The sessions were recorded and made available online afterwards. Despite this, live attendance was satisfyingly high - greater than 50%. Note that the VLE system does not facilitate the collection of a register, so precise attendance is impossible to measure. Anecdotal feedback from students suggests that they found it 'enjoyable and entertaining' and even a 'highlight' of their day! The live format added some spontaneity to the event and this has been appreciated by students watching the recordings.

The Cleanroom technical staff were also in attendance at the vLabs. They assisted with setting and answering technical questions. It also enabled these staff to gauge the level of understanding of the students and hence to be better placed to help with marking and giving feedback on the post lab tasks.

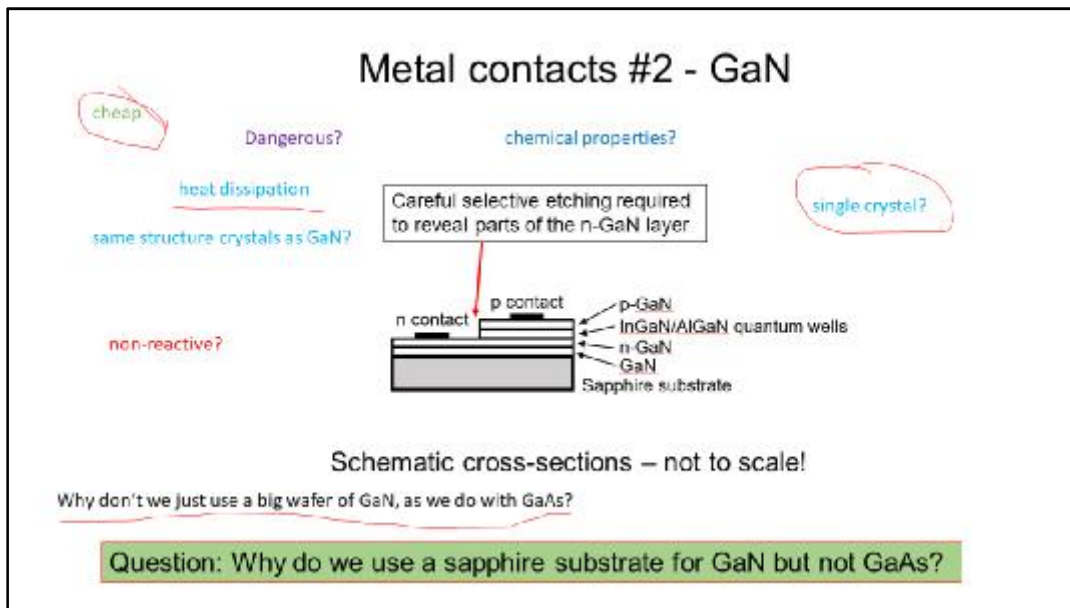


Figure 4: Screenshot of student-annotated slide from live virtual Cleanroom lab (reproduced)

7 Circuit design

An independent circuit design, construction and testing task would normally form the capstone of the practical exercises for first year electronic engineers, but as most students do not own specialist soldering and measurement equipment at home, this cannot be directly replicated remotely. Even where students may have their own equipment, the University cannot verify that their equipment is serviceable and will be used safely, so no expectations for practical work could be made. To still teach the fundamentals of circuit design and testing, students were provided with several simulation exercises. Two freeware platforms were selected for this task, based on their wide compatibility and ease of installation: LTSpice and Tinkercad. A structured series of sessions was designed for the students to complete at their own pace, including initial guided tutorials instructing on how to use the platforms. Particular focus was placed on how to simulate realistic circuit effects that would be seen in the laboratory, such as hidden internal resistances and parasitic capacitances, rather than just illustrating ideal theoretical concepts. The final sessions required the students to perform an independent design exercise and then simulate tests of their circuit's performance against set criteria; this mirrored requirements of the original practical exercise, with the omission of only manual soldering practice.

Student interaction and engagement was maintained by frequent online quizzes, which included a mixture of both automated feedback from numerical answers, and personalised feedback from staff on images and design files shared by the students. This balanced feedback structure allowed rapid turnaround of a realistic marking

workload for staff, despite a cohort of 80 students. The combination of exercises and quizzes allowed learning outcomes in engineering design and experimental testing to still be met and assessed, even without physically constructing the circuits. Students should be able to progress smoothly into second year practical work, which will directly use the skills that students have acquired. However, students will need to translate their measurement techniques from virtual on-screen instruments to physical equipment, which will require careful instruction. All simulation exercises will also be integrated into pre lab work when laboratories reopen, allowing students to become familiar with circuit designs and expected results before attending in-lab sessions, to increase efficiency and value of the in-lab practical experience.

8 Control and instrumentation

One of the challenges of quickly moving the control system analysis and design laboratories onto on-line delivery, was to find a method to facilitate the control system design elements of the activities, and allowing the students to analyse the subsequent performance of the real system. The goal was to create temporary on-line replacement activities, that closely mirrored the activities printed in the students' laboratory worksheets, that were provided at the start of the teaching semester.

It was required that these activities maintain the pre laboratory: analysis, design, and linear system simulation elements, but also provide the students with quality feedback to enable them to correct any misunderstandings or wrong working, without just giving them the answers. This way, the student learning journey and intellectual development unfolds in a similar manner to how it would have if either a GTA or lecturer were present to catch any wrong working or misconceptions. Thus, in normal times, the students are facilitated in reaching their end goal, understanding how they got there and have received feedback on any mistakes made and can progress to a correct understanding of this topic.

To quickly facilitate this delivery, each activity employed a blend of demonstration videos (Figure 5), sample data sets taken from these demonstrations, and on-line quizzes with quality feedback to ensure the students have measured the correct values, analysed the data correctly, and showed understanding of the results. A key factor to these activities was the structured sequence of the presentation of this material, which was facilitated using the Backboard VLE.



Figure 5 Screenshot showing experiment and response.

The activities were split into sections, with successful completion of quizzes used to adaptively release material (using this facility in Blackboard) for the next section. Students were required to complete the worksheet section, alongside the demonstration video, before starting the quiz for that section. Design sections had an initial quiz before the release of the remainder of the material and final sectional quiz. This allowed design of the controller gains calculated by the students to be assessed before the 'instructors' values were revealed in the demonstration video.

Each quiz was automatically marked and high quality feedback was provided to students to help correct any mistakes. The quizzes were generally a blend of multiple choice, numerical value, multiple answer, or jumbled sentence questions. Students needed to get full marks in each quiz before they could move on, but had unlimited attempts at each quiz.

For each incorrect answer, feedback was provided to the students, signposting them to background resources in the worksheet, VLE or course lecture notes, and, if necessary, they could email the academic for further advice or signposting. This allowed students to make mistakes, but through engagement they could persevere and truly understand the subject and how it related to real systems.

9 Robotics

The University of Sheffield had invested £400k this year in new state-of-the-art robotics hardware to provide undergraduate students with industry-relevant, hands-on practical robotics experiences. A brand new 12 week practical lab course had

been developed around this hardware and this was being delivered to second year Computer Science undergraduates for the first time. With the curtailment to face to face teaching occurring in the middle of this, an alternative approach needed to be devised, which maintained a level of continuity to the partially-delivered course but without access to the physical hardware.

The open-source robot simulator *Webots*¹⁴ was selected as the most appropriate platform to deliver a simulation-based alternative to the practical laboratory sessions. The students would have originally, in groups, programmed their real robots (using Python) to complete a series of tasks in a *final challenge* at the end of the semester in a real physical environment (a *Robot Arena* located in one of the departmental laboratories). Using *Webots*, a representative robot arena could be simulated, so that students could still learn how to develop the same core robot behaviours that would fulfil the original challenge so the original LOs were still achieved. A number of benefits were in fact identified as a result of this simulation based approach. Firstly, a series of separate *'development arenas'* (Figure 6) could be provided to the students to allow them to develop and test individual robot behaviours in isolation, before amalgamating these into a single, multi-layer controller.

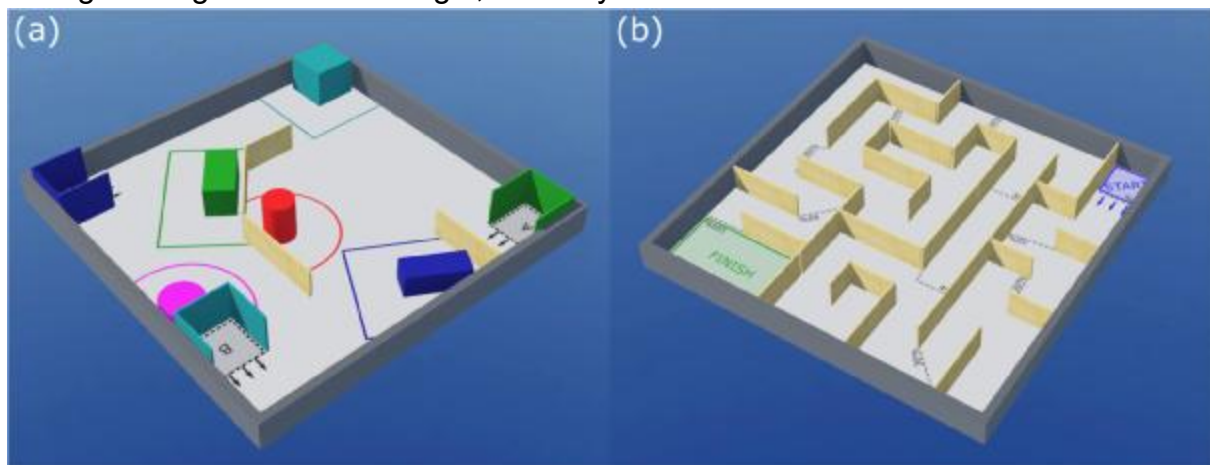


Figure 6: Robot 'Development Arenas' for (a) object search and detection and (b) maze navigation

Secondly, these were distributed to students via a VLE, and they therefore had unrestricted access to develop and test whenever they wanted to, rather than being limited to scheduled lab hours. Finally, an additional element was also introduced into the assignment where students were required to actually develop robot hardware from scratch in the simulator as well, thus also exercising their ability to consider the physical and geometric constraints and the further technical requirements of the final challenge too (the requirements and limitations of sensors and actuators for instance). Some student robots are shown in Figure 7.

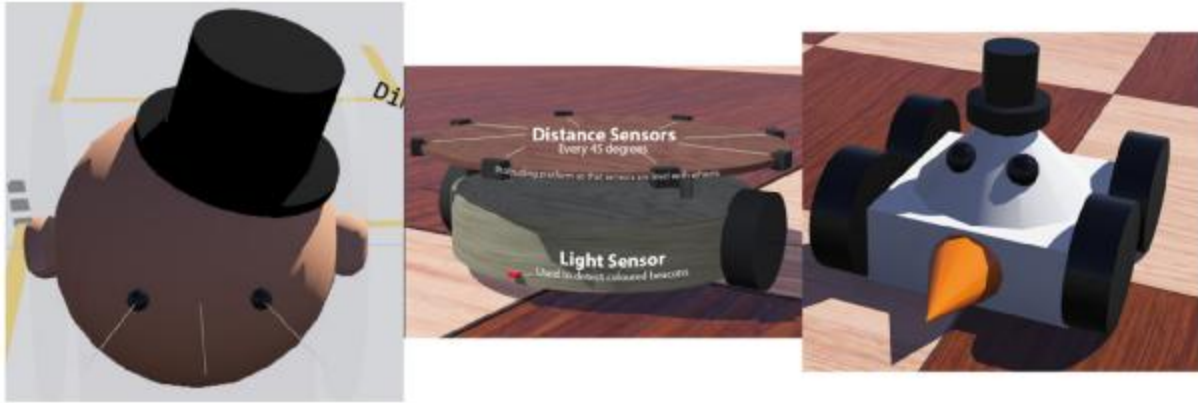


Figure 7: *Examples of some innovative student-designed robots*

The use of a VLE was at the heart of this work. Detailed lab instructions were released to students and updated regularly through this, as well as all the necessary simulation files for students to develop and run their robots in Webots were provided. A discussion board was set up to provide a forum for students to post questions. It was monitored regularly by laboratory and module leaders, and GTAs so that support and guidance could be provided to students in a timely manner. This was found to be very effective, providing a space for students to voice questions and concerns (technical or logistic) and for activity facilitators to address such topics and publicise responses without having to reiterate to students individually.

Whereas the original assessment would have been based on showcasing their robot's performance in the robot arena, students were submitted videos of their robots performing the equivalent tasks in the simulator instead. Staging intermediate task submissions at various points throughout the lab course was an effective method of checking student progress and monitoring overall engagement. In the final challenge, the students will submit their robot and multi-layer controller scripts for entry (by activity facilitators) in a competition, using an arena configuration that the students do not have prior knowledge of, thus testing the robustness of their developed robot behaviours. They will be ranked in a league-based competition, and a video of their robot's performance will be provided to them once the competition has taken place.

Overall, the transition to online delivery of what would originally have been very much a practical hands-on laboratory experience has highlighted a number of potential advantages. Indeed, it is clear now how certain simulation-based elements could be introduced into the course to further support the practical sessions and enhance student learning in the future.

Discussion

The sudden appearance and effect of the coronavirus has caused major disruption to the education sector. Generally, this is not a good thing for the student

experience, but it can encourage teachers to think outside the box. It could provide the impetus to create approaches that they have not previously had the time or opportunity to investigate. This is particularly true of practical sessions and laboratory experiments, where students engaging with equipment, working in groups and making mistakes are crucial elements of the learning process. This is most important where experimental work is embedded into courses and provides some of the LOs.

As the numerous case studies (CSs) provided in this paper show, a number of approaches can be used to mitigate the loss of the actual practical experience, such as take home experiments, remote control of equipment, technical staff carrying out experiments for the students, simulation and video replacement of the experiment. Due to the large number of experiments that needed to be moved online in a short period of time, and the existing infrastructure, MEE decided to quickly record experiments for students work from. It will be seen from the variety of strategies used, that positioning remote practicals as a valuable learning experience rather than a recording of the experiment is key to getting students to actually engage with and understand the experiment. Simulations, remote face to face sessions, quizzes, real and simulated data, gamification, and edited videos for students to collect data from all allow engagement at a higher level. This allowed the experiments to be more interactive than just using videos to show what was happening. To corroborate the findings of the literature survey. It is easier to provided substitute and remote laboratories where there is a computer between the equipment and the user. In this case, true remote experimentation is possible. This is why most of the previous examples of remote experiments are in the field of electronics and control.

It is unlikely that this would have been prioritised in “normal” times. So, as well as providing a simulacrum of a practical experience, the work put in at this time will actually improve the student experience in the future, because much of the material produced will be used to enhance our pre labs to prepare students better in advance of the laboratory activities. For example, extra information and practice can be provided by videos on analysing data which will be available for students going forwards to support their learning, such as described in CS1.

It must be reiterated that these replacement activities will not be able to substitute for and support all the skills that quality graduate engineers need. Indeed, the UK Engineering Council in its accreditation documents¹⁵ has a complete section on Engineering Practice where one of the requirements is the “Ability to apply relevant practical and laboratory skills”. It is clear that this cannot be conducted purely through electronic means. If it turns out that students cannot attend university campuses for a period of years, these will need to be provided for in other ways, with the associated Health and Safety aspects of working unsupervised. Without the addition of copious resources, remote practicals will generally only be able to supply some of the skills needed to function as engineers in the workplace. For example,

commercial pilot training is now provided almost exclusively using simulators, but this is both low volume and very expensive.

Moving practical teaching online presented us not only with the challenge of how to provide the students with the experience and skills that each practical session offered originally, but also how to get the essential feedback from the students about their engagement in these activities. Previously we could easily receive verbal feedback from the students during the laboratory practicals, either directly from them or through our GTAs. MEE developed a system for recording student satisfaction anonymously during laboratory activities where they simply press one of four facial expressions displayed on a tablet to indicate how they feel about the activity they have just completed. This has allowed us to identify the practicals that the students struggled the most with and modify them for subsequent cohorts. Away from the lab, both of those channels of receiving student feedback have been blocked just at the time when the mode of delivery was disrupted.

To mitigate that a simple Google-based feedback form was created that students are encouraged to fill out after each online activity. The form was written in a way that it can be completed in under 2 minutes to encourage as many student responses as possible. There are only 7 compulsory multiple-choice questions to which students can reply on a Likert scale and 2 optional open-ended questions concerning the specifics of what they liked about the activity and what we could do to improve it. The multiple-choice questions ask the students whether they know and can do more after completing the online activity, understand why this activity is part of their degree programme, whether the instructions were clear enough for them to complete it successfully and whether staff were easily reachable if any problems arose. Crucially the form also asks the students whether they believe that the online activity was an adequate replacement of the practical activities under the current circumstances, and even whether they think they gained comparable skills and understanding to what they would have in a laboratory.

The information that we had and continue to gather will help us not only to improve our online delivery of some of the laboratory teaching in the new academic year, which is likely to be required, but also rethink and redesign our activities for the future. For example, it will be possible to assess whether the LTSpice and Tinkercad approaches described in CS7 gave the students comparable skills and understanding to a practical laboratory experience. If true, then we could continue to provide basic circuit design teaching in this way and utilize the staff, laboratory and financial resources that would have otherwise been required for this to instead offer students face-to-face teaching of more advanced industry-based concepts and/or more creative open-ended projects that truly benefit from interactive teaching.

Due to the strict time constraints, it was not possible to obtain ethics approval to report on student feedback we received on the strategies we implemented, so only

anecdotal evidence is supplied. However, as stated in CS5, the lack of student complaints and the completion rates (CS5) is a first order indication that students were engaging with the experiments and finding them useful.

We were in a good position to be able to move laboratory teaching online as MEE is a department dedicated to delivering high quality practical teaching and our student body is used to carrying out pre lab activities online. This meant that it was possible to take a reasonably unified top level approach, combined with a myriad of ways of delivering and engaging the students, to move away from face to face laboratory experiments, while still being able to implement our high quality teaching within a very short timescale. We hope that readers of this paper will be inspired by some of the ideas presented here and will be able to better support students who can't physically access laboratories to gain practical experiences. Some of the material and approaches developed will also be used to enhance the student experience in the future and ensure that when they are able to access the physical spaces they enter them better prepared to use that valuable and expensive time more effectively in their development as practical, employable engineers.

Conclusions

The approach of using the University of Sheffield's VLE to support student practical experience when face to face teaching was curtailed appears to have worked. MEE's aim to deliver original Learning Outcomes and to continue to support modules with embedded practical activities was conducted effectively.

Due to the existing infrastructure and MEE's previous experience, it was possible to video experiments, write quizzes, create new simulation tutorials, and provide other supporting documentation in a very short time. By empowering staff within a framework, suitable local solutions were developed by individual members as well as teams to address a wide range of requirements.

Recordings of laboratory experiments will never substitute the in-person activities, but by thinking about the Learning Outcomes and the student experience, it is possible to create an effective learning environment for a short to medium hiatus in lab availability.

A variety of approaches to remote practicals have been presented. It is recommended that further work be undertaken to codify the totality of options for delivering online practicals, including the aspects of in lab activities that are suitable for delivering in a remote format and those that can only be delivered adequately using face to face teaching. This work would allow the development of a toolkit of tactics for educators to consider when required to either pivot completely to online learning or highly limit the amount of time each student can spend in laboratories due to social distancing measures

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Appendix

10 Cement making

For the case of the cement making and testing it was decided that a video of the experiment was the best way to get students to engage with the topic. This shows the materials and procedure for making cement mortars with different water, cement and sand ratios and the testing of the cured materials using splitting tensile testing technique. This was more than sufficient to allow students both to answer the Blackboard post lab quiz that is based on statistical analysis of brittle materials and to submit a histogram of supplied data from previous tests. These are all the things that students would have been asked to do after the conventional face to face session.

11 SEM instruction

To help the students to understand the process of operating a Scanning Electron Microscope (SEM), we developed a video which explains how to load the sample correctly, take topographic images of a porous material and do an energy dispersive X-ray (EDX) analysis on a steel alloy. This will be a very useful tool for future training of undergraduate and project students and will be incorporated into the pre lab for the SEM sessions.

12 Biopharmaceutical Engineering

Biopharmaceutical Engineering practical laboratories were moved online by conducting a video recording of the whole experiments the students would be expected to do, demonstrating all aspects that had been laid out in the experimental protocols. The whole video was then edited with comments and captions added in places to make it clearer, along with the voice, where necessary. The video was edited to make it concise and compact so that the students would find it interesting and also help to understand and answer the post lab questions. Questions were set and sent to students according to what was expected as an outcome of what they learnt from the video as an experimental and post experimental activity. If some parts of the experiment could not be recorded in the available time, then relevant data was simulated or acquired to supplement them. Examples of some of the experiments which we intended to deliver under the normal circumstances and could deliver a very good understanding of the activity online are the “Antibiotic Production” (Figure A.1) and “Fermentation kinetics” (Figure A.2) experiments.



Figure A1: Set up of the antibiotic production experiment.

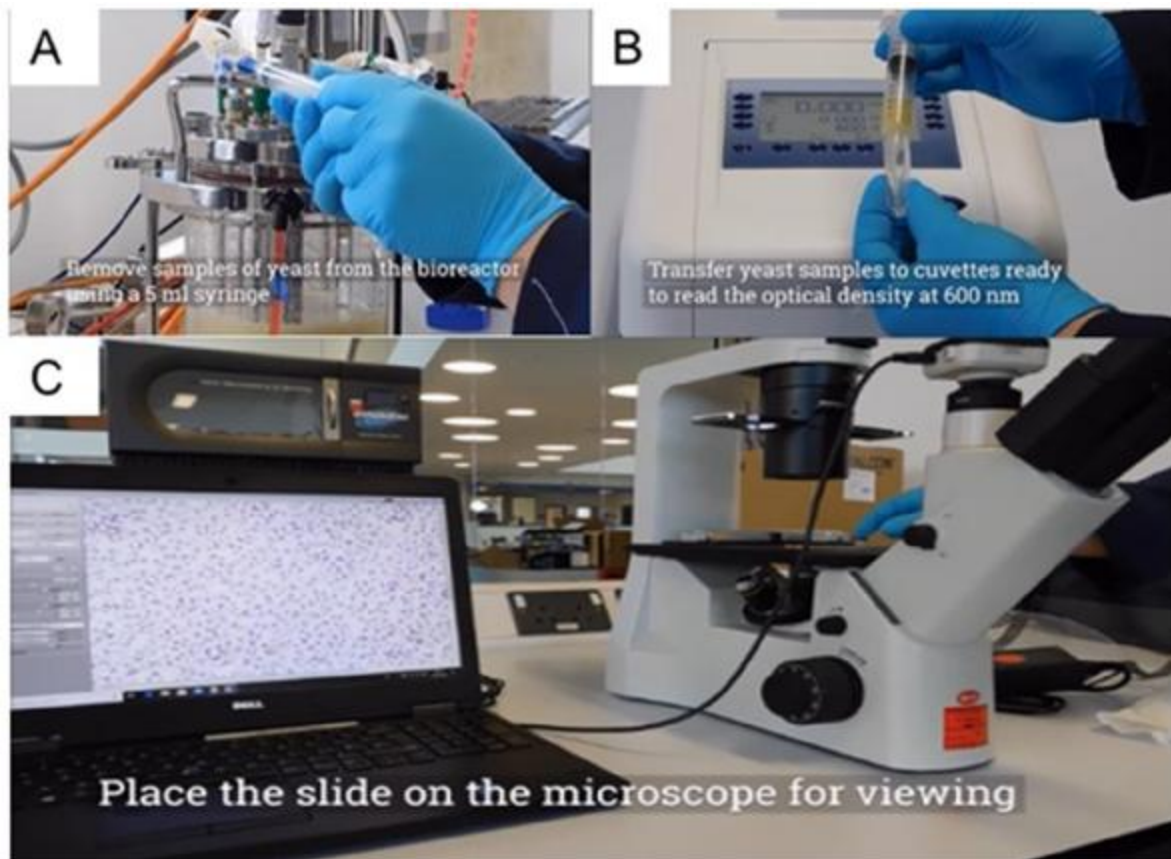


Figure A.2, (A) is the fermentation kinetics experimental setup, (B) to Using the spectrophotometer. (C) The stained yeast cells from the bioreactor.

Additional information and knowledge was delivered through lectures either by recording or live stream. Books that were not available in the online library, were requested from the library to make them available online. After every week's lecture, students were tested by an online quiz and short essay questions.

The online teaching saved a lot of time by demonstrating the experiment a single time for a large cohort of students. In future, live streaming the experiments with some of the online monitoring tools could be added, which will allow the students to manage experiments online, similar to a hands-on experience. This will augment the practical skills that they learn.

13 Bioreactor Engineering

Bioreactor Engineering forms a part of the 3rd year Chemical and Biological Engineering module entitled “Reaction Engineering 2”. The LOs of the “bioreactor engineering” laboratory session were centred around students gaining a practical understanding of how bacteria grow in controlled conditions using an industrial scale bioreactor, as well as on the analysis of data to identify correlations between different parameters relating to the bacteria within the bioreactor. The experiment consists of an interactive demonstration of the bioreactor to small groups of students. During these sessions students would be asked to identify relevant measured and controlled signals, before collecting a sample of the bacteria culture from the bioreactor and measuring the optical density (OD) using spectrophotometry. Following this, the students would be presented with a data set from a previous bioreactor fermentation run and expected to identify correlations between various measured parameters and calculate values, such as specific growth rate.

Online, a video was created explaining the functions of the bioreactor, showing key parts of the equipment and explaining how measurements of the culture inside are made. Screen captures of the human-machine interface were included in this video and students were instructed to pause the video at certain points to note down key values from the screen captures for use in an online test (Figure A.3). The video included a member of technical staff demonstrating manual sampling and OD measurement of the culture, which the students were again instructed to record.

A data analysis instructional document was prepared for the students, explaining what data analysis they should perform on the provided sample data set. To improve students proficiency in working with large data sets, students were provided with a video on how to “clean” data and instructed to reduce the number of data points. Student performance was assessed using a test on Blackboard that required students to make calculations using the “clean” processed data. Feedback was given automatically to correct any mistakes.

Through the creation of the online content to support this laboratory session, all LOs were able to be met. The online delivery of material also allowed all students to receive the demonstration, albeit without the hands-on aspects, simultaneously, overcoming the issue of limited space within the laboratory itself. The lack of requests for clarification regarding both the video demonstration and the analysis exercise, coupled with the high average grades in the VLE quiz, indicates the

students gained a good understanding of the material covered online, as they would in the laboratory session.

CPE360 - Bioreactor Engineering



CPE360 - Bioreactor Engineering



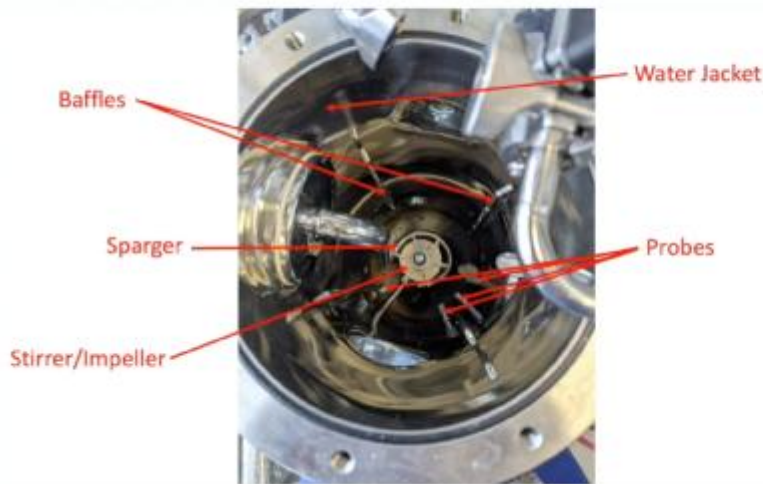


Figure A.3: Screen grab of teaching material provided to students

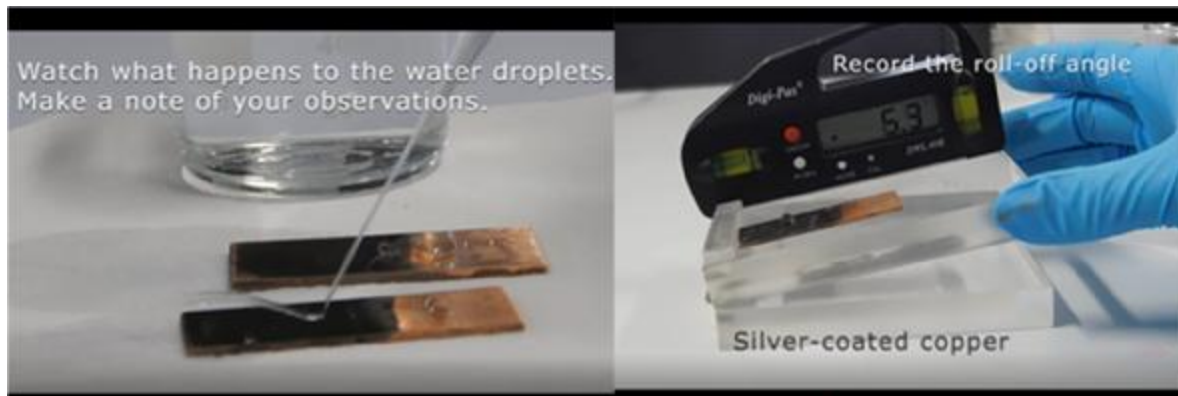
14 Fabricating a superhydrophobic surface

As part of Bioengineering and Materials Science students' regular practical education, students investigate how biomaterials can be modified for various biomedical applications. Normally, they do that by fabricating a superhydrophobic surface, investigating the water contact angles of several different materials using two different methods, and then evaluating the methods and the results.

Without access to the laboratories and to meet the LOs of this lab based learning activity, a video was created of the experimental procedure that demonstrates the fabrication of a superhydrophobic surface, as well as demonstrating the two methods used to measure the water contact angles on seven different materials (Figure A.4). The video had instructions for students to make observations and record the measurements from each method, so that students could still evaluate their results as they would have done had they been able to attend a practical lab session in person. Students were required to submit their observations, table of recorded measurements and summary of the results, including a comparison of the accuracy of the two techniques used to measure water contact angles and a rank order of materials in terms of hydrophilicity/hydrophobicity through Blackboard for assessment, and feedback was provided to each student in the cohort.

Students had completed all parts of this online learning activity and evaluated the results successfully. Valid statements on the accuracy of the techniques used in the experiment were made, including the impact of experimental errors on the recorded measurements. The answers provided by students were more comprehensive than what would normally be given during a face to face lab session, possibly due to less

time restraints. Therefore, this online activity could be used in future for assessment as an alternative to attending a session, such as in a resit.



A

B

Figure A.4. Screenshot showing the (A) the properties of a fabricated superhydrophobic surface and (B) investigating hydrophilicity and hydrophobicity.

15 Frictional losses in pipes

Due to the empirical nature of the fluid mechanics involved, the frictional losses in pipes experiment traditionally involves the collection and processing of many data sets by students to find coefficients. In order to meet the Learning Objectives (LOs) in this instance, raw sample data previously collected by staff using the same equipment was provided to the students for further processing. In addition, an extensive pre lab activity, showing the layout, function, operation and instrumentation of the equipment used as well as a detailed lab sheet explaining the aim and procedure to collect and process the data was included. A video and step by step instructions explaining the origin of the data, including the fact that it may contain experimental errors, was provided on the VLE to ensure students fully understood how the activity had been augmented from the original description and the alternative tasks they should perform. In addition, a live video conferencing session, using Blackboard Collaborate, was set up at the same time as the original timetable session to allow students to interact with staff and discuss questions they had about the lab. While the material allowed students to work asynchronously, the live sessions provided an opportunity to encourage a completion of the tasks as a group, and partially recreate the sense of community often found during face to face practicals.

16 Mohr Circles for a hole-in plate

The main LO of this experiment is data analysis (drawing Mohr's Circles). The experimental part, consisting of the tensile test of a plate with a round discontinuity in

the centre, usually takes only up to 25% of the overall session time. It was thus decided to drop the experimental part and focus entirely on the data analysis for the online replacement activity.

A dataset available from a previous year was uploaded on Blackboard, together with additional visual support including a sketch of the geometrical parameters (intended to give some context to the provided data (see Figure A.5 top left)) as well as the same plot of strains over time that students would get were they in the lab (see Figure A.5 top right). Students were referred to the instructions provided in their lab sheet to complete the data analysis (see a student drawing in Figure A.5 bottom left). In addition, the expected numerical and graphical solutions for the provided dataset was made available to the students (see Figure A.5 bottom right), but with a caveat. Taking advantage of the adaptive release offered by the Blackboard VLE, such solutions were only available to students that completed the online pre lab activity as a measure intended to ensure a sufficient level of preparation before engaging with the practical. Finally, to support students in the completion of the data analysis, it was decided to opt for a one to one discussion via email, when necessary.

The outcomes of the summative assessment suggest that the measures put in place were effective with most students doing very well. Two main considerations are required when deciding whether this type of approach is viable. Firstly, replacing the experimental component with a dataset was only possible because the session primarily focused on data analysis. Secondly, engagement may become a problem when the approach described above is applied to non-assessed sessions as it lacks live interaction with students. Measuring student engagement remotely is tricky. One option could be looking at the enquiries made by students for a specific session. The aforementioned approach was similarly implemented also for a non-assessed session; however, in this case, no student queries were received as opposed to the daily ones for the assessed session. Another method could involve implementing an easy quiz that would replace the requirement for students to be physically present in the laboratory to effectively pass this activity.

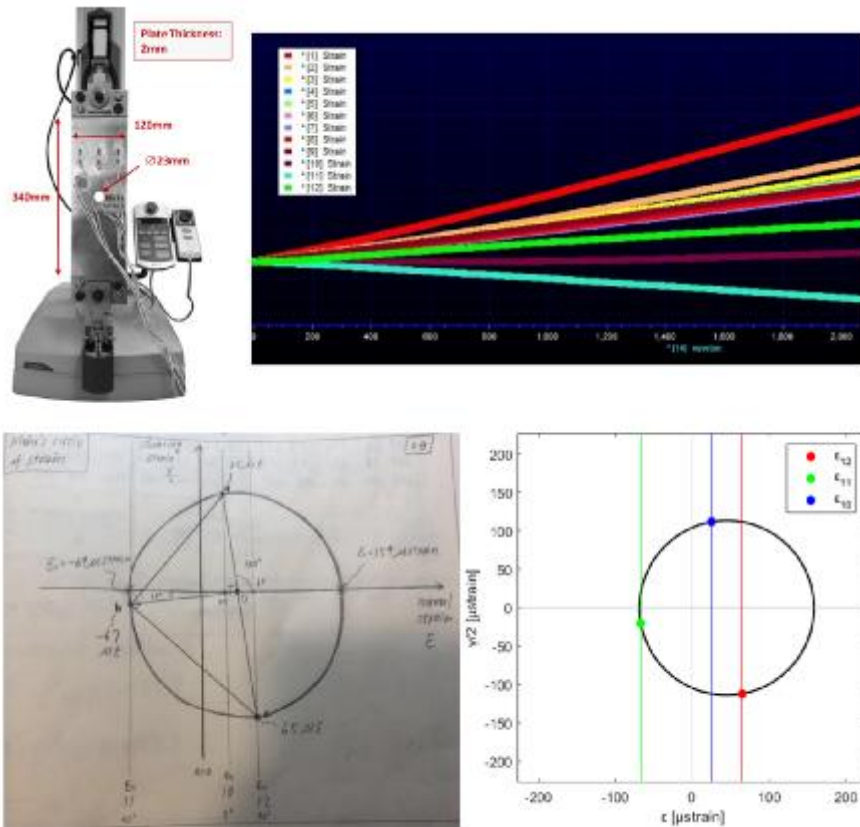


Figure A.5 Example of information provided to students and some student work (used with permission)

17 Jet engines and the Brayton cycle

One of the key parts of engineering is the application of the theoretical to the physical. Managing this process is key to the manufacture of complex systems, such as a jet engine. To this end, we have a running jet engine within MEE, that is used principally by first and second year aerospace engineers. This sits in a sound-proofed engine test cell, within a dedicated propulsion lab, smelling suitably of kerosene. As such, it serves two purposes, in one it is a complex machine, but in the other it is an example of the laws of thermodynamics; it is a link between the real and the ideal.

In their first year thermodynamics module, the last subject covered by the Aerospace Engineering students is the Brayton cycle, allowing them to look at the performance of a jet engine in ideal and real situations, and thus work out the efficiency of the machine. This is taught in the lectures, where it is assessed by an online test. However, to complete the experience and show how real systems work, the engine itself provides an example, the understanding of which better prepares the students to undertake that online test, as they have seen, smelled and heard the engine operate, before taking data to process from the real engine.

Clearly moving online was not possible with the engine, and the explanation of the real machine was potentially lost. However, a video was prepared, starting with a cut-away model of the engine, moving through the test cell and explaining the test engine's instrumentation, before showing students the data acquisition system and discussing the test protocol (Figure A.6). This allowed the students to see how the data was collected, but also to understand how the data was measured, and in which part of the engine the necessary sensors were placed. In actuality, this is highly representative of the experience of practicing engineers, who would often be remote from the testing of things they had designed. Hence, the move online provides us with a further learning outcome in practical engineering.



Figure A.6: Screenshot showing operating of the engine

Test data obtained in the video that they watch is provided for analysis, and the method of calculation is explained in a laboratory script. However, the data from the engine is left in the original format so that values need to be converted to consistent units, and some factors need to be calculated using equations that the students have previously employed. The general principle is that the data should be as pure as possible, so that the students have to work out the steps necessary to perform the calculations themselves. Following this, a quiz is provided as a self-test and so they could obtain feedback if they are struggling. Successful completion of this quiz opens up the online assessment test, such that they have every opportunity to complete the assessment even in the absence of the intended hands-on experience.

The Science and Engineering Foundation Year (FY) programme at the University of Sheffield provides a supportive learning environment to improve students' understanding and skills of STEM subjects in preparation for degree-level study. The first FY experiment impacted by suspension of face to face teaching was optics. Normally, refraction and diffraction are investigated in the following experiments with an optics bench:

- i) Calculate the refractive index and critical value for an unknown material
- ii) Investigate the behaviour of light through a diffraction grating and determine the wavelength of different parts of the white light spectrum

In the refraction experiment, a video replaced the experimental setup and introduction to the optics bench (Figure A.7). Students were tasked to construct a data table suitable for refraction and reflection measurements and collect data from high resolution photographs, ensuring their data was to an appropriate level of precision. Students graphed their data and used Snell's law to calculate the refractive index from the gradient.

In the original diffraction experiment, students would sight along a diffraction scale to determine the position of different colour maxima in the spectrum of white light. This posed more of a challenge to provide an online version where students could collect their own data. As an alternative, video teaching was used to illustrate the equipment setup and procedure. Students used a provided raw dataset to calculate the wavelength of red and blue light and gain an appreciation of how to deal with measurement uncertainties.

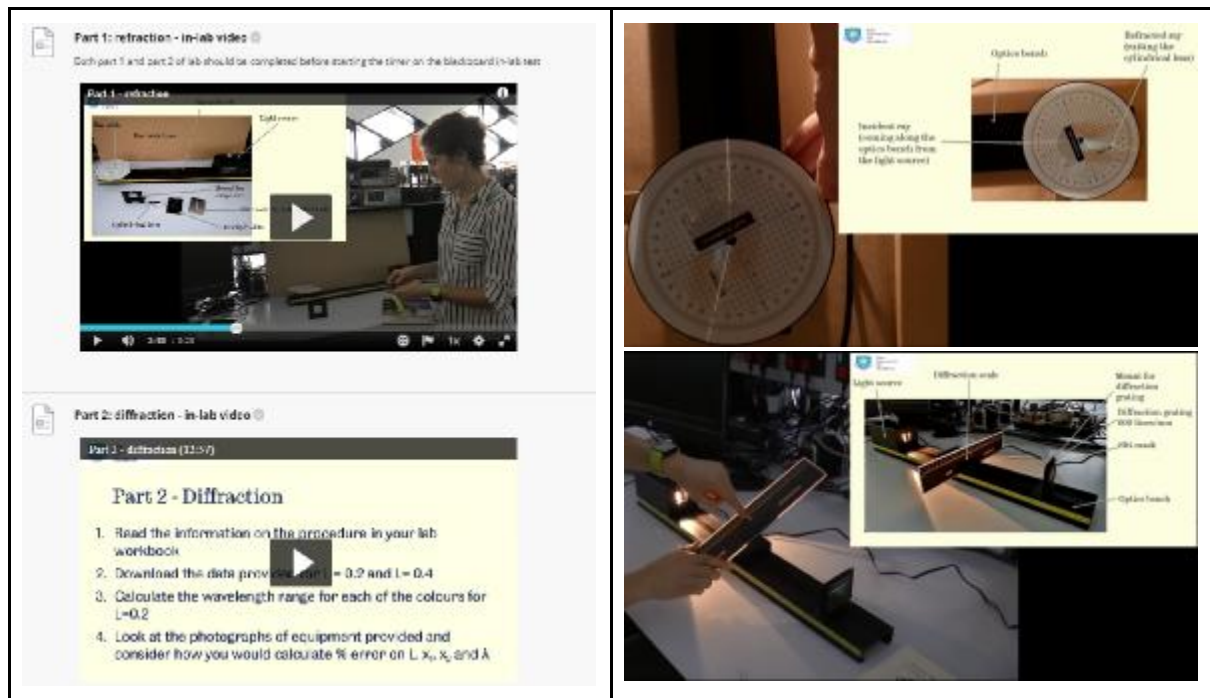


Figure A.7: Screenshots of online optics lab materials

The post lab activity aimed to foster collaboration between students to regain some of the community lost by lack of physical presence in the lab. To facilitate that, students were encouraged to work together to devise methods for answering the post lab questions, however, each individual was tasked with solving their problem with a unique set of operating conditions using the Blackboard 'calculated formula' capability . Questions focused on calculations relating to scientific and engineering applications of refraction and diffraction, including fibre optics, star spectra and the eye.

Moving these experiments online gave the opportunity to assess our student's understanding in a more robust manner as it removed time constraints and logistical issues of getting students into and out of the laboratories. Initial impressions of engagement indicate that it was almost identical to previous face to face sessions.

19 Electrical machines and drives

Moving online at a fast pace, faced us with the challenge of transforming a series of experiments pertaining to the field of electrical machines and drives, involving relatively large industrial-grade equipment, into virtual online lab activities. The series of experiments demonstrate the use of different types of electrical machines as controllable electromechanical energy conversion devices and investigate some of their fundamental operating characteristics. During the tests, several measured quantities are recorded and are used to derive other key machine parameters either directly or by using the corresponding equivalent circuit model of the machine type under investigation.

Normally, students would perform a series of tests through a LabVIEW-based program that controls the machine set via their associated drives. These experimental tests have been recorded in the lab by following the step-by-step instructions from the existing lab script. The recorded footage has been edited into full video demonstrations of each experiment, providing students with insight on how the required measurements are obtained, by simultaneously viewing the control interface and the test rig (Figure A.8). Animations, captions and annotations have been incorporated in the videos providing students with guided instructions and highlighting key points. Datasets with the required measurement values for each experiment have been provided to students for subsequent analysis and interpretation. Students were required to follow the lab script while going through the video content and perform the required calculations/plots for each experiment.

Induction Machines & Drives

Test 2: Locked-rotor test



Locked-rotor
equivalent circuit

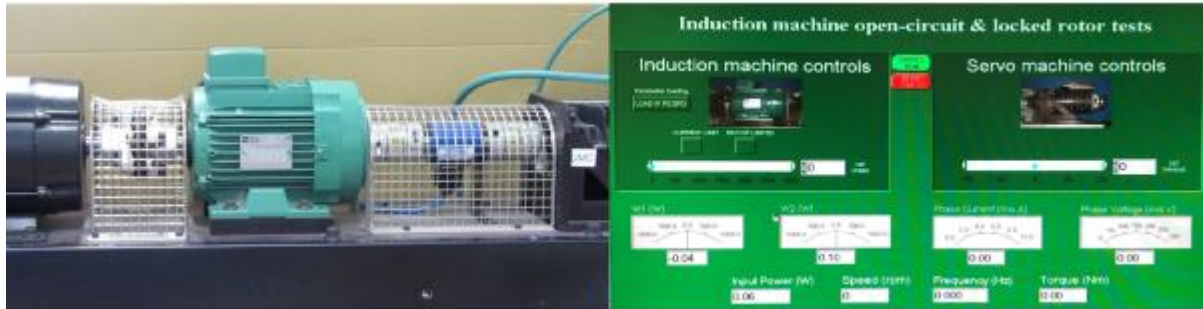
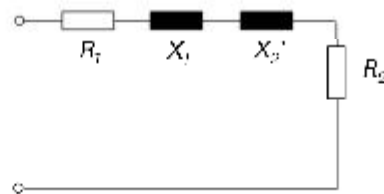


Figure A.8: Screenshot from the video demonstration of an experimental test

In an effort to engage students more fully, reinforce their overall understanding of the experiments and emulate the interaction of students with GTAs that would normally take place in the lab, a self-assessed online lab quiz was developed, adding to the existing pre- and post-lab quizzes. This quiz was intended to enable students to validate their calculations as well as enhance their knowledge on the topic. This quiz was unassessed, and students had unlimited attempts to complete it. The questions contained in the quiz were organised thematically. The correct answers were never revealed upon submission. Instead, automated feedback was incorporated for incorrect answers, guiding students toward finding the correct answer, enabling them to learn from their mistakes. The feedback took various forms, such as signposting students to a relevant resource (e.g. lab script, theory) and/or targeting common student errors (e.g. steps omitted, approach). Students requiring additional guidance and support were encouraged to contact the academic. However, this was a rare occurrence.

The attempt statistics of the self-assessed quiz showed a high-level of student engagement with the material. The post-lab assessment results indicated that students who completed the online lab activities performed comparably well in assessment to those who completed the activities in the lab. This is encouraging and indicates the benefits of incorporating a self-assessed quiz to emulate interaction with staff alongside video demonstrations. Future sessions, both remote and in-lab, can use this blended approach to enhance the students' learning experience and engagement.

20 Extra-curricular electronics

Students from across all engineering disciplines require basic skills in practical electronics, and these skills are generally no longer provided by secondary schools. In particular, students are not proficient at building small prototype circuits or confident in exploring electronics concepts by practical investigation, despite enthusiasm to do so. Providing optional extracurricular sessions in a supportive environment, with trained staff to guide students through fun training activities, can provide a valuable introduction to practical electronics.

A regular series of optional drop-in practical electronics workshops in the laboratory has been running in the Wednesday afternoon timeslots traditionally reserved for extra-curricular activities at UK universities. These sessions have proved popular, with students from 6 different departments regularly engaging. Bespoke teaching material has been created for these sessions, focussing on practical construction and applications of electronic circuits rather than theoretical or mathematical approaches. Students have attended to develop their practical skills or construct independent projects. However, with the suspension of face-to-face teaching, the regular in-lab sessions had to be cancelled.

Ensuring extra-curricular activities continue during remote teaching helps maintain a sense of community between students, and ensures that interesting and engaging parts of the courses are not neglected. The teaching material has therefore been moved to a publicly accessible website¹⁶, which includes five separate sections: 1) basic electronics theory and brief explanations of basic tools and equipment, which also includes any associated Health and Safety (H&S) aspects, 2) description of essential practical skills, such as soldering, 3) examples of circuits, which students are free to build, test and modify, 4) tutorials on using a microcontroller system (Arduino) allowing students to learn to build and program simple to complex electronics-based systems, and 5) examples of projects for students to undertake in the future. The site includes text, photo and video content, presented in the same informal and encouraging style of the in-lab sessions.

The site actively encourages the use of practical making skills, and provides a parts list and advice for students on obtaining kit or components. However, it is also possible to use circuit simulation software, such as LTspice and Tinkercad to complete a large part of the provided exercises. Students can access the materials at any time of day and are able to work at their own pace. They can also choose which activities best suit them and they are encouraged to ask questions (via email or video chat) to further develop their own interests.

Since the sessions were previously advertised via word of mouth in the laboratory sessions, and physical posters, the promotion campaign moved to social media, with support from university departments and faculties to encourage students to engage. Social media has been particularly active on Wednesday afternoons, replicating the previous buzz of activity in the laboratory at that time. In future, the online teaching material can support the regular in-lab sessions to encourage students to develop

their own interests and practice their skills both inside and outside the laboratory at any time.

¹⁶ <https://sites.google.com/sheffield.ac.uk/diamond-electronics/home> (Accessed 27/05/2020)