Practical approaches to delivering pandemic impacted laboratory teaching

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Abstract

#DryLabsRealScience is a community of practice established to support life science educators with the provision of laboratory-based classes in the face of the COVID-19 pandemic and restricted access to facilities. Four key approaches have emerged from the innovative work shared with the network: videos, simulations, virtual/augmented reality, and datasets, with each having strengths and weaknesses. Each strategy was used pre-COVID and has a sound theoretical underpinning; here, we explore how the pandemic has forced their adaptation and highlight novel utilisation to support student learning in the laboratory environment during the challenges faced by remote and blended teaching.

Keywords: *community of practice; laboratory teaching; videos; simulations; AR/VR; datasets.*

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1. Introduction

COVID-19 forced higher education institutions to rapidly reconsider their approaches to and delivery of lab-based teaching. As face-to-face teaching was suspended and moved online, one of the main challenges associated with practical-based disciplines, which traditionally have relied on the fundamental development of psychomotor skills, was how to provide meaningful lab experiences for students remotely (Wilkinson *et al*., 2021). #DryLabsRealScience (#DLRS) was set up, by the authors, at the start of the pandemic to address this issue and provide a supportive network for life science educators looking to share innovative approaches to overcome the challenges of being unable to access facilities and equipment. What has emerged is a much richer community of practice that enhances the way that practical delivery is approached in a broader sense (Francis *et al*., 2020).

The network has an international reach of over 200 educators spanning higher and further education, teachers in schools and colleges, students, and commercial education resource providers from a wide range of disciplines, including biosciences to engineering. The network's ongoing success, as measured by continuing participation and resource development, lies in bringing together practitioners by providing an openly accessible platform with an underpinning ethos of freely sharing ideas and resources. This ethos has helped break down siloed teaching and resource development approaches, resulting in a more engaging learning experience for students and enhancing the pedagogic approaches to practical delivery. Over 90% of participants highlighted that attendance at network events had allowed them to influence their departmental policy to dry lab provision (Cramman et al., 2021). Resources developed by the network are collated on lecturemotely.com and YouTube, allowing access to materials beyond the original presentations and reaching the broadest possible audience. The lasting impact of the network is illustrated by the evolving pedagogic approaches to practical class provision as educators adapt to a blended model of teaching delivery.

2. Approaches

Thematic analysis of the content delivered during the #DLRS meetings highlighted four main categories of approaches: videos, simulations, AR/VR, and datasets. These themes clearly overlap each other and have been used in combination to deliver and supplement the practical experience. Each theme has its own theoretical underpinning and application at the macro level. Below we set out the context in which these resources were used pre-COVID, followed by how they have been adapted and utilised to navigate the challenges caused by remote laboratories. Examples will be included as a supplement to the narrative. A conceptual framework describing these themes is set out in figure 1.

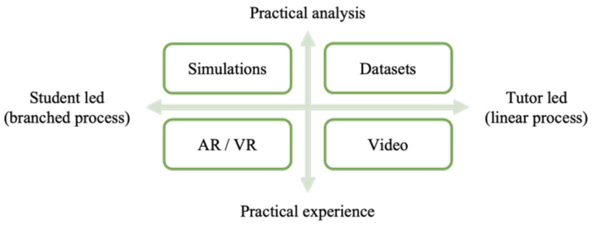

Figure 1. The four main areas of practice can be split along two axes. The first axis describes the pathway for interaction with content: tutor-led (linear process) where a defined outcome is pre-set, and student-led (branched process) where the outcomes are dependent on the actions of the individual. The second axis describes a dry laboratory as either a physical experience where the aim is to replicate or enhance the psychomotor components of conducting a practical, or practical analysis where the aim is to generate or manipulate practical outcomes.

2.1. Videos

Educational videos are integral to many higher education courses, whether integrated as part of the curriculum in traditional courses, as a precursor for ‘flipped’ courses or as a principal delivery mechanism for blended/online courses. Video has been shown in many studies to be an effective educational tool (e.g., Woolfitt, 2015). They have been used in a wide range of higher education contexts such as teaching (Kay & Kletskin, 2012), tutorials (He *et al*., 2012) or feedback delivery (Mahoney *et al*., 2019). Educational videos have previously been recognised for their potential to supplement or augment practical pedagogies, such as the use of video exemplars and practical guides (Crocker *et al*., 2010; Long *et al*., 2014).

During the COVID-19 pandemic, the initial transition to remote teaching of practical classes and later restricted access to labs led to an intense focus on the use of video to support delivery. The main approaches employed by the #DLRS community can be considered in the three stages of a typical practical i) pre-lab (e.g., health and safety briefings, theoretical background, equipment usage), ii) replacement labs (e.g., videoing a whole practical and live ‘point-of-view’ experimental run-throughs) and iii) post-lab (e.g., data visualisation / capture and data analysis) (Turner, 2020).

Using video as a medium is not without challenge, Fyfield *et al*., (2019) summarised that video must manage the cognitive load on the learner and maximise student learning by promoting active learning opportunities. Members of #DLRS explored specific active learning approaches to effectively using practical based videos. Examples include:

1. Errors. The introduction of deliberate ‘errors’ into a practical video. Students watch the video, identify mistakes, and reflect on their impacts. Such exercises can be supplemented by synchronous discussion activity sharing observations or by watching an additional error-free video (Lab Science Resources, 2022).
2. Silence. The production of a practical video without audio. Students write or record their own explanations to demonstrate their understanding of the processes being demonstrated.

3. What happens next? Create a deliberately incomplete practical video by either stopping the video before the end or leaving out critical steps. Create formative exercises around these, asking the key question, “what should happen next?”.
4. You make the choice. Live stream practicals and use student questions or commentary as a learning tool to guide the actions (Lab Science Resources, 2022).
5. Quizzes. Build questions into the video that must be answered correctly before a student can continue watching (Lab Science Resources, 2022).

2.2. Simulations

A simulation is a model that mimics the operation of an existing or proposed system. Within the laboratory practical context, this manifests itself as a recreation of a method or technique, often in a digital form (Jones, 2018). Simulations vary from interactive videos or step through guides because the outcomes are dependent on the start conditions, leading to branched possibilities. Simulations also serve as a means to allow students to gain experience in methods or techniques that would otherwise be time-consuming or limited by accessibility.

The use of simulations in practical teaching is a form of inquiry-based learning (Pedaste *et al*., 2015), where students are focused on iteration within the simulated environment. Students are required to manipulate parameters within the stimulation, record and then analyse the observed outcomes (Gormally *et al*., 2009). Simulations allow students to experience a methodology prior to performing it within a physical laboratory, an approach that has been demonstrated to enhance student learning (Keskitalo, 2021; Blackburn *et al*., 2019). Through passing ownership and control of the experience to the student, they can direct the task, acting in an authentic manner and experience research skills like problem-solving (Bassindale *et al*., 2021). These traits can then be transferred to the physical environment when the student enters the lab as they have, in effect, already experienced what is required to solve a given problem.

Virtual lab simulations can link scientific theory and laboratory practice in the same way physical labs do, in some cases more so, because you can perform many more iterations in one day than in a physical lab. Students report that they develop: data analysis and problem-solving skills, an understanding of correct equipment usage, alongside record-keeping, all of which align closely with the learning objectives for a wet lab module (Bassindale *et al*., 2021). Examples include:

1. Data recording. Simulations are used to generate electronic lab notebooks through a [Do][Explore][Act] framework consisting of three levels of tasks/commands (Bassindale *et al*., 2021).
2. Labster (www.labster.com). Interactive virtual labs allow students to explore a given scenario or method through a gamified 3D learning virtual environment.

3. Virtual learning tools. Benchling (www.benchling.com), a free, cloud-based software platform, was used to provide a virtual lab experience. Originating as a research tool, Benchling incorporates electronic lab notebooks and a suite of molecular biology analysis tools; it was adapted to work as a virtual learning tool, helping to emulate a variety of scientific processes (Lab Science Resources, 2022).
4. OpenSTEM labs (www.stem.open.ac.uk). Online virtual lab in collaboration with the Wolfson Foundation. Investigations are based on onscreen instruments, remote access experiments and virtual scenarios using real data.

2.3. AR/VR

Virtual reality (VR) is a technology that creates a real-time immersive simulated environment. In contrast, augmented reality (AR) integrates digital information allowing simultaneous interaction with virtual objects with the physical environment (Huang *et al.,* 2019). VR as a pedagogic tool is well studied (e.g., Radianti *et al*., 2020) and has been specifically applied in both compulsory science education (Tan & Waugh, 2013) and higher education (Huang *et al.,* 2019). Several international commercial providers (e.g., Labster, Learning Science (www.learnsci.com) and the OU Open Labs) provide virtual laboratories, combining VR, simulations with videos, worksheets, and active learning tools. Although used widely in some disciplines, AR is more emergent as a pedagogic tool in life science, though its potential in this discipline has been explored (Barrow *et al.,* 2019). The #DLRS community recognised the benefits of VR/AR to replace and supplement practical teaching. However, it acknowledged several barriers to initial adaptation, including the cost of equipment, IT infrastructure of the institution, access by students to IT hardware and technology skill set. Specific examples of VR/AR include:

1. The creation of 360º videos using ArcGIS StoryMaps for virtual field trips allows students to connect with multiple fieldwork sites (Lab Science Resources, 2022).
2. The development of a virtual marine field trip using ThinkLink. The VR field site allows students to navigate a coastal landscape and conduct real-time experiments by using embedded videos and experimental tools (Lab Science Resources, 2022).
3. Enhancing both physical and VR coastal survey experiences by creating AR specimens as they appear when undertaking data analysis (Lab Science Resources, 2022).
4. The creation of four AR protein structures to help students visualise key concepts from lectures. Created using Zapworks by exporting crystal structure of proteins from Pymol (Lab Science Resources, 2022; Reeves *et al.,* 2021).

2.4. Datasets

Fundamental to the laboratory practical experience is the analysis of data sets. Pre-COVID, much of the practical experience in physical laboratories was concerned with generating numerical data sets or images, which were later processed and analysed. Within the post-laboratory teaching settings, statistical analysis is typically applied to the data set, allowing meaning to be extracted. As such, the ability to work with data is a key practical skill. Within the #DLRS context, datasets are tutor generated using simple coding strategies in R, C++, or HTML, rather than practically generated and analysed by the students.

In this way, each student was assigned their own numerical data set to work with, with solutions provided to the tutor based on the initial parameters. By providing effectively limitless data sets, students have the opportunity to develop their skills in data processing and analysis, with unique data sets limiting the opportunities for collusion. Specific examples of datasets showcased by the #DLRS community include:

1. Automatically generated data sets were created in R. Specific variables were randomised, with a set range and errors introduced to create the data set. Each data set was given a unique identifier linked to a solutions sheet (Lab Science Resources, 2022).
2. HTML Interactive experiments generate datasets on a range of core biological topics within a web page environment. Students analyse and input these datasets into the web page for automatic marking (Lab Science Resources, 2022).
3. Smart worksheets are held within a virtual learning environment. The worksheets were commercially generated by LearnSci and were used to develop students' mathematical abilities. Each worksheet is unique to the student and provides feedback based on the submitted answer (Lab Science Resources, 2022).
4. High Content Image Analysis students were provided with existing cell images and used the open-source CellProfiler to perform image analysis (Lab Science Resources, 2022). Images were unique to the student.

A potential downside to computer-generated datasets is a lack of ownership felt by the students and, therefore, more limited engagement with the data. Synthetic datasets may not exactly mimic trends seen in laboratory-generated data and there can be an increased marking burden for staff unless work is electronically marked (Lab Science Resources, 2022).

3. Concluding remarks

COVID-19 forced a rapid evolution of the pedagogical approaches underpinning practical class delivery. As educators began to adapt to the challenges posed by the pandemic, new ways of integrating the different strategies described here were adopted. During the initial transition to online teaching, many of these approaches were adopted in isolation; however, we are now seeing a more joined-up approach with multiple approaches combined to dramatically enhance the pre-and post-laboratory experience for students. The strategies described here cannot fully replace practical provision, nor should they try to, as the kinematic skills developed during laboratory classes are essential skills required in science-based disciplines. However, where they add immense value is in scaffolding the preparatory phase, allowing students to better appreciate the theory and application of techniques prior to even setting foot in the laboratory. Data analysis and interpretation are core skills for any scientist, and here, again, student learning can be enhanced post-class allowing for a far richer educational experience.

Although the approaches are described here in the context of biosciences, they are applicable to many other disciplines within and beyond STEM. The main benefit of communities such as #DLRS is the provision of an inclusive, open platform that promotes the free sharing of ideas and resources, allowing the adoption, refinement, and enhancement of teaching strategies. The impact of the networks will last long beyond the end of the current pandemic, fundamentally changing the pedagogic thinking around laboratory provision based on the continuing use of resources following a return to more normal laboratory delivery methods.

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