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Exploring the utility of virtual laboratory training tools

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ABSTRACT

The global COVID-19 pandemic catalysed a sector-wide shift towards online distance education, and in the years that followed, the mass proliferation of online learning resources made it possible to use virtual laboratory training to both augment face-to-face laboratory practicals and to provide a stand-alone, immersive learning experience. This article reviews currently available resources, their application to different teaching modes and potential learner benefits.

Keywords: blended learning, laboratory simulations, laboratory skills, online learning, problem-solving, virtual laboratories.

Introduction

The global COVID-19 pandemic catalysed a sector-wide shift towards online distance education, and the initial Emergency Response Teaching (ERT) primarily focused on online adaptation of lectures, tutorials and assessment strategies.[1] Conventional wisdom suggested that authentic laboratory training could only be completed in person; hence, hands-on clinical and laboratory training was delayed or cancelled for large cohorts of students.[2] In the years that followed, the mass proliferation of online learning resources made it possible to use virtual laboratory training to both augment face-to-face laboratory practicals and to provide a stand-alone, immersive learning experience. Through demonstration videos, students can pre-visualise experimental workflows, before attending their in-person laboratory classes to carry out those experiments; they can also interact with virtual laboratory simulators to explore additional experimental conditions and troubleshoot points of failure following their live class.[3,4] Learners can also engage in experimental planning and collect and analyse data for which they are responsible,[5] thereby building critical-thinking skills through the experience of productive failure and iterative cycles of redesign and execution. By using blended learning pedagogies – mixing face-to-face and online instructional modes – virtual laboratory training can be integrated into the science curriculum as part of a holistic learning experience for both students and instructors.

Blended laboratory learning through video

Laboratory practical sessions are the most interactive form of hands-on learning, and can span a spectrum of student autonomy and complexity.[6] For first-year university students new to scientific inquiry, however, laboratory classes can be overwhelming because of their high cognitive load, which can limit a student's ability to retain new information.[7] However, the use of multimedia can help support complex learning tasks.[8] According to Mayer's Multimedia Theory of Learning, videos serve as an effective instructional tool because of the dual channel principle: the simultaneous presentation of sound and imagery that allows learners to efficiently process information by visual and verbal channels concurrently.[9]

Laboratory demonstrations serve as an ideal topic for educational videos as laboratory equipment can be filmed, labelled on screen, and used to perform each step of an experimental procedure with accompanying instructor explanations.[4] Students can pause, fast forward and rewind to different parts of the video to focus on their individual gaps in understanding. Furthermore, such pre-training of chemical names, reagents and equipment, as well as the segmenting of experimental details into memorable portions has been shown to improve student learning.[10,11] Prior to coming to the lab, students can repeatedly view detailed video demonstrations of specific laboratory techniques along with instructor explanations of their theoretical implications. These online learning experiences can aid in the familiarisation with equipment and techniques, which expedites the development of proficiencies in physical skills. This blended-learning approach can maximise the value of face-to-face practical class time.

It is important to consider though that video production is a labour- and resource-intensive endeavour, and individual instructors might not wish to reinvent the wheel and make new videos for every laboratory class. For those in this category, in addition to the archive of videos published in the *Journal of Visualised Experiments* (see https://www.jove.com), science educators can access resources curated by the Australian Council of Deans of Science through the online repository (see https://www.acds.edu.au/teaching-learning/resource-repository/). Specific videos focusing on laboratory teaching in microbiology, can also be sourced freely from the 'Microbiology Teaching videos at NUI Galway' (see https://www.youtube.com/channel/UCsP4xz5aq7sWfR9eXSCd_QQ)[12] and 'BioLab Collective with Jack Wang' (see https://www.youtube.com/c/biolabcollective).

Virtual troubleshooting and problem-solving

Mastery of practical skills and an ability to troubleshoot problems are a cornerstone of successful careers in science, technology, engineering, and mathematics (STEM) disciplines. The inquiry-based learning processes involved in repeated iteration and execution of experimental procedures can bolster scientific literacy and student confidence,[13] but the benefits of these learning activities are not always available to all students. Practical instruction of students is often limited by the availability of laboratory spaces, as well as the high staff and consumable costs associated with practical education. This means that students usually carry out experiments only once and are unable to acquire essential employability skills in troubleshooting and data analysis,[14] which develop by engaging with the optimisation of an experimental process.

The challenges of this learning environment can be supported by blended-learning approaches that promote troubleshooting, critical reasoning and problem-solving competencies. Students can use virtual laboratory 'workbenches' to simulate experiments an infinite number of times, both before and after attending in-person laboratory classes. Virtual laboratory simulators can log student interactions with the system and generate clickstream data, which can be fed back to students. The analysis of such online interactions can be incorporated into student reflective assessment tasks, which can promote independent and creative thinking when coupled with undergraduate research experiences.[15]

There is a broad spectrum of virtual laboratory resources available on the market. These include stand-alone animations of foundational scientific concepts (e.g. Biointeractive, PHET) as well as visually sophisticated online environments (e.g. Labster, Praxilab, Learning Science, CaseIt, Avida-ED). A summary of these platforms is given in Table 1. Despite excellent graphics and guided narrative structures, learners usually encounter a single, pre-defined, linear workflow that progresses through a fixed sequence of actions without variation. Although such simulators can create familiarity with types of equipment and their uses, they do not allow the learners to develop a sense of the inherent complexity and adaptability required for authentic laboratory research. However, there are virtual laboratory simulators that more closely mirror the consequences in a real laboratory environment – for example the Lab Data Generator (Table 1) – which allows students to carry out actions in a self-selected order and to even make mistakes to further develop their understanding. The Lab Data Generator was used to deploy a virtual module on antibiotic resistance testing, which facilitated improvements in student learning gains.[5]

Table 1. Virtual laboratory simulators.

Resource	Website
Biointeractive	https://www.biointeractive.org/
PHET	https://phet.colorado.edu/
Labster	https://www.labster.com/
Praxilab	https://praxilabs.com/
Learning Science	https://www.learnsci.com/
CaseIt	https://www.caseitproject.org/about-alt/
Avida-ED	https://evolution-outreach.biomedcentral.com/articles/10.1186/s12052-016-0060-0
Lab Data Generator	https://garethdenyer.github.io/LiqHan/

Data collected from online simulations can leverage the cloud-based collaborative functionality of Electronic Laboratory Notebooks,[16] which are quickly becoming an industry standard, and can be used by both students and instructors to retrace their steps and identify possible sources of error. In addition to providing a critical, blended expansion to traditional laboratory practicals, virtual lab 'workbenches' can also secure delivery of authentic practicals to students when delivery of face-to-face practicals is not possible.

Conclusion and future directions

Technology-enabled learning can be daunting for science educators, but high-value online educational resources should be embraced by the sector. The landscape for both open source and commercial tools in this space is rapidly changing, as are the economics for their large-scale adoption. The rise in augmented, virtual and extended reality environments will continue to change the value proposition for face-to-face laboratory training.[17,18] By attempting to integrate novel approaches in laboratory training, institutions can assess their impact on the development of higher-order scientific skills. This will allow the sector to pre-empt the next wave of technological innovation and upscale the global accessibility of science education.

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Data availability. The data that support this study are available in the article.

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Assoc. Prof. Jack Wang is a teaching-focused microbiologist at The University of Queensland. His work focuses on undergraduate research and technology-enabled assessment in science education. He was the recipient of the 2020 ASM David White Teaching Excellence Award and was named the 2020 Australian University Teacher of the Year.