Post COVID Foundation Biology through Interactive Online Learning

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***Abstract*—The rapid migration of courses from blended teaching to a fully online learning environment during the COVID-19 pandemic required the timely development of new, online teaching resources and re-imagined strategies, to teach practical skills to university students. The move to deliver content that was fully online challenged the assumptions and conventions about the use of face-to-face classes, especially in STEM disciplines that rely on experiential learning. This critical review uses case studies to describe the innovations that were used to adapt undergraduate, first year (foundation) biology courses which were previously delivered using a blended learning pedagogy to a fully online format. In doing so, the opportunities to enhance traditionally practical based activities have also been considered. Future innovations for blended learning, however, require inherent properties and capacity of technologies to support aligned learning tasks. Reflections on the crisis response to learning however, act as a catalyst for educational change towards more flexible models and practices in future interconnected learning environments.**

***Index Terms*—blended learning, e-learning, undergraduate STEM, virtual laboratory, experiential learning**

I. Introduction

In March 2020, universities were propelled into online-only teaching due to government restrictions imposed due to the global COVID-19 pandemic. To maintain student learning and progress, as an interim step, most university courses deployed emergency, fully online, learning resources [1]. Changes to the dominant mode of delivery extended for some campuses until the end of the year, while others increased their online presence. Online learning (e-learning) is the use of internet and other technologies to develop materials for educational purposes, instructional delivery and management of programs [2]. However, the rapid shift to deliver content that was fully online prompted a challenge to conventions about the use and value of face-to-face (F2F) classes, especially in STEM disciplines that rely heavily on experiential learning and resulted in abandoning traditional practical student experiences. For teaching institutions with a prevailing online delivery, complete remote teaching is not usually offered in STEM disciplines which regularly require the physical on campus presence of the students for both practical and assessment aspects of courses [3].

Globally, many higher educational institutions use e-learning to enhance the learning experience and strengthen the instructor roles in education. Blended learning, which is the integration of F2F and online instruction [4], has become a standard practice and widely adopted in higher education [5], [6]. Blended learning facilitates learning more readily than either F2F or fully online courses alone through the considered and complementary integration of F2F and online technologies [7]. Student choice and flexibility is key to a blended learning pedagogy, providing freedom about when and where students participate in the online portion of their course. This flexibility embedded into the delivery and learning program results in higher student satisfaction than in either fully online or F2F courses. Undergraduate students perceive that they learn better in blended courses than in F2F courses across a variety of undergraduate disciplines and class sizes [8]-[10]. However, within robust practical and inquiry-based courses such as in the STEM disciplines, successful analytical skills and the development of conceptual knowledge are best combined with direct or timely guidance [8], [11].

The rapid transition to a fully online teaching environment during the 2020 COVID-19 pandemic dictated that the benefits of the F2F component of the blended learning model needed to be addressed to maintain existing learning outcomes, especially for courses in industry accredited degrees. This required the development of exclusively online communication with students together with new strategies to teach traditionally practical based skills to undergraduate students using e-technology. This review will first summarise the current understanding of the benefits and issues in blended learning compared to e-learning strategies in STEM undergraduate courses in which practical based activities are considered essential. Our experiences about the transition of first year undergraduate biology courses from blended delivery to exclusively online delivery is presented as case studies and will consider:

Manuscript received March 12, 2021; revised June 8, 2021.

doi: 10.18178/ijlt.7.2.154-165

a) The initial rapid transition from blended learning into online only delivery of content whilst maintaining the learning outcomes required for student success and
b) A more considered development of content required to convert blended STEM delivery into online only STEM delivery for introductory biology courses.
c) Finally, the benefits and disadvantages of blended learning and online instruction in STEM disciplines will be considered.

II. Current Trends in Blended Learning

Blended learning is broadly defined as the complementary integration of F2F and online facilitated learning to effectively deliver learning material to students that enables their education [7]. The terms hybrid learning, and mixed mode teaching are other common terms for combined delivery in F2F and online modes. Within the tertiary education setting, blended learning can range from whole course structure within an online learning management system (LMS); to part F2F and online learning activities; to the use of forum and discussion boards for communication with teaching staff and peers [12].

In a world of technology and digital communication, blended learning has become a well-researched and published topic across a wide range of academic disciplines and academic levels (e.g. [13], [12]). Student perception of blended learning is well documented [14], with comparisons between blended learning to traditional delivery or to fully online courses [15], and more recently studies of the proportion of time spent online in a blended course [16]. A comprehensive approach to a wide variety of models and methods to blended learning are covered in a couple of key publications and will not be addressed here [12], [17].

The perceived flexibility in access to learning through course e-learning software and LMS have been associated with positive student satisfaction of online lessons. Many students select to study online courses because the asynchronous learning offered by e-learning is more flexible with the work-life-study balance of individual students [18]. Asynchronous e-learning has further been shown to better support cognitive participation, improving reflective participation and deep learning as students have more time to consider and reflect on concepts [19]. There is also substantive evidence in the literature that students enrolled in blended courses tend to modestly outperform their counterparts in traditional F2F courses [20]. According to reference [21], e-learning potentially strengthens both the learners and instructor's role for developing community by developing new communication channels. The latter is illustrated with the greatest benefits in a blended approach for the mature student, for lifelong learning. Learners can also access e-learning resources multiple times thereby enhancing deeper comprehension of course material [19].

In contrast to mature students, the generation Z, born in 1997 or later, whose distinctive quality is a strong relationship with information and communication technologies (ICT), have a different learning style to many students from the past. They are multitaskers, web searchers, and active learners, and wish clear employment trajectories. Digital competency is a key attribute for the current and future workforce and will be required for life long and changing employability [22].

To address the needs of different student cohorts, in the past, the modes and methods of the two learning environments remained largely separate. F2F teaching was mostly teacher directed within a synchronous personal setting whereas distance learning emphasised independent, self-paced and self-directed learning in an asynchronous distributed space. Further, with the increasing element of digital learning technologies and computer mediated instructional methods, many undergraduate and postgraduate courses are commonly conducted with a mixture of online methods together with opportunities for synchronous F2F interactions and guided e-learning activities [23].

III. Blended and E-Learning Methodologies in STEM Disciplines

The teaching of science, technology, and engineering is lagging in the adoption of new technology for the delivery of teaching material (e.g. [24]), in part due to the requirement of laboratory activities necessary for vocational training [25], [3]. A major hurdle that must be overcome before STEM courses can be delivered solely in an online environment is the development of realistic laboratory and fieldwork simulations that approximate actual physical experiences to equip students for innovation sector employment. Either the real lab needs to be enabled for remote completion as it is the case for kitchen science or it needs to be replicated as a fully software-based virtual lab [26]. However, the development of these resources requires significant investment in time and resources [27].

Perceptions of STEM students from both quantitative and qualitative surveys, were found to be less positive than their non-STEM counterparts for a shift in dominance towards e-learning despite STEM students performing significantly higher than non-STEM students [28]. It is likely that STEM students felt less positive because they lacked connection with their peers and their instructor. Nevertheless, several studies demonstrated that STEM and non-STEM students perceive blended learning courses more positively than their counterparts enrolled in courses that were delivered using traditional and expository methods [29]-[31].

Recent technological innovations such as gamification, augmented and virtual reality technologies have the potential to revolutionise STEM e-learning education through the development of realistic lab and fieldwork simulations. Reference [27] discuss important features of e-technologies which enhance students' learning experience and form a conduit between real labs and virtual labs. Furthermore, virtual labs are predicted to ease the lab maintenance cost burden on universities [32]. F2F laboratory experiences often require specific expertise of the teaching staff and are time-consuming and costly for institutions to manage [25]. In contrast, well planned relevant virtual laboratory simulations have been found to increase students' knowledge, skills and performance in examinations, while reducing limitations of distance, health and safety, and expense. For example, virtual labs have the potential to be used in experiments that would have high safety risks [33]. Another benefit is that virtual lab simulations can be used to test hypotheses by generating experimental data. To be truly effective in training students in data analysis these lab simulations need to produce experiments complete with natural variation and experimental error estimates [34].

IV. Challenges of the Online Science Practical Experience

Tertiary institutions are looking for innovative ways to enhance the student experience through the development of meaningful and engaging online activities. However, these virtual lab simulations are currently used to augment and not replace student learning in actual laboratory experiments (e.g. [26], [34]). In order to achieve the expected learning outcomes in STEM, technology should be complemented with an appropriate learning activity, as technology by itself does not develop student competencies [35]. It needs to be accompanied by appropriate pedagogical strategies and assessments permitting timely and continuous feedback and allowing the student to achieve the expected mastery of the competency [22].

The biggest disadvantage of most virtual lab simulations is that they do not accurately simulate the sensory and tactile reality of the lab or field experience. However, as augmented reality technology advances, this may become less of an issue [3]. Currently, in the biological sciences, the reality of physically handling specimens, live organisms or the preparation of lab reagents cannot be realistically experienced in virtual lab simulations. For example, prepared microscope slides engage the student in interpretation of structure in ways that photographs, and animations cannot [36]. Further, the health and safety aspects of STEM education are particularly important during the foundation years of higher-level education. To prepare safer, STEM-literate graduates safety concepts and guidelines need to be explicitly included in academic standards and outcomes to ensure curricula, lessons, assessments, instructional practices, and teacher preparation programs address these important concepts [37].

The incorporation of virtual lab simulations into STEM education often requires adjustment or extension of existing simulation resources that are currently available. Therefore, in addition to mastering discipline-specific knowledge, teachers are also required to understand the simulation technology required for deployment. However, mastering the simulation technology by the teacher is not required if the institution is prepared to invest in third party resource simulation providers or partner with in-house learning designers, programmers, and graphic artists to develop and deploy online lab simulation content [38].

V. A Model for Rapid Change

All these issues were brought to the fore in 2020 due to the Australian Government imposing lockdown restrictions in response to the COVID-19 pandemic. This forced the rapid replacement of blended learning delivery of content with online only delivery for first year biology while maintaining similar learning outcomes for the students. To summarise the transition from the typical blended learning programs for both existing on-campus and off-campus cohorts, the model below illustrates major differences in key aspects of the learning modes (Fig. 1). The on-campus blended learning experience is supported with an online LMS for administrative and forum-based communications. The majority of learning is synchronous and F2F with structured weekly and class paced learning activities. Instructor assistance and peer support through F2F practical and tutorial activities are fundamental to this mode of learning. Conversely, the off-campus student cohort although having the equivalent online LMS for administrative and forum-based communications, complete many activities asynchronously at a more flexible pace. Learning is therefore enabled rather than supported by online delivery for this cohort of students. The timelines for assessment submission are often extended for the off-campus cohort and the ratio of instructor to student support is much higher, with only unit coordinator and topic lecturer's online communication through the LMS forum or direct email contact. Subsequently, off-campus students use the peer and instructor supported forums more regularly than on-campus students. During a typically 3-4 day intensive school students have the opportunity for F2F high impact support from the academic staff and in small groups in both practical laboratory and tutorial sessions.

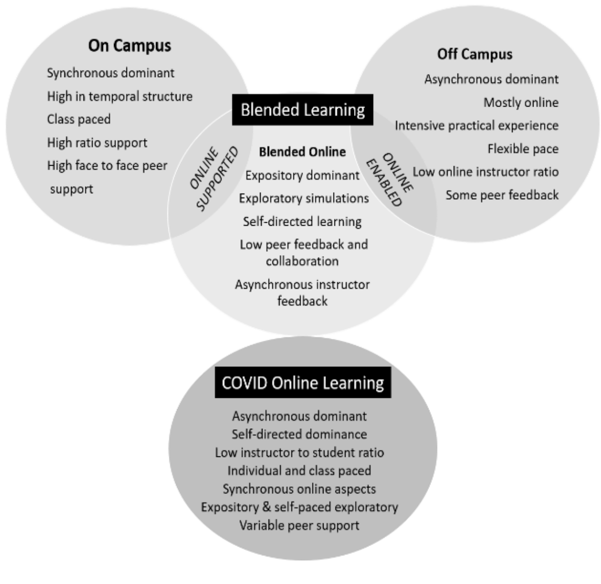

Figure 1. Model of the transition from typical blended learning programs of existing on-campus and off-campus cohorts to fully online delivery in STEM in 2020.

The common aspects for the online component of units to both cohorts is the expository delivery of traditional lecture content. Although offered F2F for on-campus students, both cohorts have access to recorded lectures. Other learning materials are predominantly both self-paced and expository or exploratory in nature and rely on self-directed learning for both cohorts with asynchronous instructor feedback. Some recent pre-laboratory activities have been developed for specific topics (e.g., Molecular Biology [26], Chemistry [39]; Lab preparation [32]). However, opportunities for peer collaboration are low for these online activities.

For the rapid development to a fully online learning mode, asynchronous communication channels become dominant for all students. Self-directed learning is required to a greater degree as the instructor to student ratio is high. Learning activities remain class paced but completion times for converted practical materials become flexible over fixed time periods. Expository online materials remain; but the key transformation is the provisions of a range of self-paced exploratory online lessons. Synchronous online aspects are added to the curriculum through real-time 'drop-in' sessions and instructor guided tutorial sessions. Online peer support networks are explicitly encouraged with augmented instructor input.

A. On- vs Off-campus Student Cohorts

On-campus and off-campus students often have different prior experiences and therefore expectations of the university learning environment [40]. Students undertaking studies off-campus often undertake their study at home from where they will interact primarily online with their unit material and teaching staff. Traditionally, on-campus teaching is synchronous with material delivered F2F and temporally aligned to student learning. Contemporary on-campus students have the resources for both a F2F and online synchronous and asynchronous learning experiences [26]. Research suggests that asynchronous learning provides a high level of satisfaction for many students, particularly regarding flexibility of time and place for learning and the emphasis on interpersonal interaction (e.g. [41]). Asynchronous e-learning is a key component of flexible, constructive, formative learning (lecturer delivery of content and interaction with learning materials) for off-campus students and can similarly provide flexibility to a traditional learning environment for on-campus students

VI. SHOWCASE: BLENDED TO ONLINE DELIVERY

A. 2019: Foundation Biology at a Mixed Mode University

We provide an account of the standard practice in foundation biology in a mixed mode university and reflection of the changes required during 2020. There are two, general first year biology units both which cover foundational content module**s,** delivered over a 15 week trimester teaching period, and were available to both on- and off-campus students (Fig. 2). Units within undergraduate courses are repeated in two of three trimesters with on- and off-campus cohorts of students.

The opening course, Biology 1, covers concepts of cell biology, microbiology, genetics and biochemistry, and animal structure and function; and is a required co-requisite for studying, Biology 2, which covers mechanisms of evolution, plant and animal diversity, plant structure and function and ecology (Fig. 2). Approximately 600 students study the initial unit and 400 in the following unit, annually. These two biology units are core to many science and agriculture courses and students enrol from a wide range of bachelor's degrees including Animal Science, Agriculture, Biomedical Science, Education, Environmental Science, Plant Science, Rural Science, Science and Zoology.

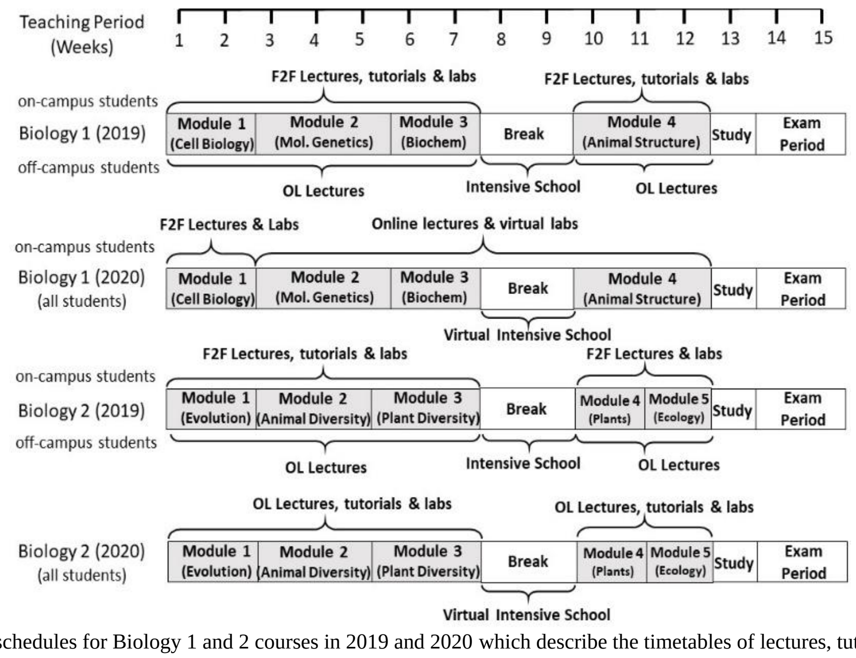

Figure 2. The teaching schedules for Biology 1 and 2 courses in 2019 and 2020 which describe the timetables of lectures, tutorials and laboratory sessions relative to the modules of the courses, the breaks, intensive schools and exam periods for on- and off-campus student cohorts

The teaching of first year biology in both units have two cohorts of students. The on-campus cohort, who attend F2F lectures on the main campus of the university and have full access to the online LMS. Most of the on-campus cohort matriculate immediately to university after completing secondary school. The off-campus cohort includes both recent school leavers and those with a vast range of life experiences who have delayed their tertiary education or are seeking to retrain. The latter cohort study the theoretical content of the biology courses completely online, with practical skills reinforced during a four day F2F intensive school which is held on the university campus mid-way through the teaching period for each biology unit (Fig. 2). Blended learning of the traditional distance learner commonly involves F2F residency.

B. Biology 1: Rapid Transition from Blended to Online Only Delivery Due to COVID-19, 2020

In a typical year, Biology 1 (e.g., in 2019) is usually offered during trimester 1 (February to June) to both on- and off-campus students (see above). Typically, on-campus students have three weekly lectures and 9×3 hour laboratory classes with tutorials scheduled over the trimester. Off-campus students attend a 4 day on-campus intensive school for the practical laboratory sessions and F2F activities, mid-way through trimester, around week 6 (Fig. 2). The standard and 2020 framework for foundation biology units taught at a multi-mode (on- and off-campus) university with blended learning synchronous activity, and asynchronous activity; and F2F activities are shown in Table I.

TABLE I. STANDARD AND 2020 FRAMEWORK FOR FOUNDATION BIOLOGY UNITS TAUGHT AT A MULTI-MODE (ON- AND OFF-CAMPUS) UNIVERSITY WITH BLENDED LEARNING. SYNCHRONOUS ACTIVITY (S); ASYNCHRONOUS ACTIVITY (A); FACE-TO-FACE ACTIVITIES (F2F).

	On-campus – blended delivery (2019)	**Off-campus – blended delivery (2019)**	**All students – online only delivery (2020)**
BIOLOGY 1			
Annual enrolments (3 year range)	**207-252**	**418-484**	**798**
Lectures	weekly F2F(S) and recorded(A)	weekly recorded(A)	weekly recorded(A)
Tutorials - mandatory	weekly F2F(S)	Intensive School F2F(S)	
Practicals (Laboratory x 8) - mandatory	weekly F2F(S)	Intensive School F2F(S)	
Assignment workshops	F2F(S) and recorded(A)	recorded(A)	recorded(A)
Discussion fora	(A)	(A)	(A)
Topic and Practical Q&A drop in			**weekly OR online intensive 4 day block (S)**
Practicals (static and interactive simulations)			**Self- directed(A)**
Online small group Tutorials (Zoom)*			**weekly OR intensive (4 day block) small group facilitated on Zoom(S)***
Practical assessments			**weekly practical worksheet e-submission and e-marking**
Essay - e-submission	e-submission and e-marking	e-submission	e-submission
Topic e-quizzes (x4)	e-submission and e-marking	e-submission	e-submission
Practical assessment	4x Lab classes(S)	4x Lab assessments during Intensive(S)	**weekly or after Intensive e-submission and e-marking**
Invigilated exam	F2F - on campus (fixed time)	F2F - remote options (fixed time)	**invigilated online exam (24 hour time slot) e- marking**

** practical submission required prior to tutorial attendance*

BIOLOGY 2			
Annual enrolments (3 year range)	**151-159**	**175-257**	**516**
Lectures	weekly F2F(S) and recorded(A)	weekly recorded(A)	weekly recorded(A)
Tutorials - mandatory	weekly F2F(S)	Intensive School F2F(S)	
Practicals (Laboratory) - mandatory	weekly F2F(S)	Intensive School F2F (S)	
Assignment workshops	F2F(S) and recorded(A)	recorded(A)	recorded(A)
Discussion fora	(A)	(A)	(A)

Topic and Practical Q&A drop in			**weekly OR online intensive 4 day block (S)**
Practicals (static, interactive simulations and outdoor activities)			**Self-directed(A)**
Online small group Tutorials (Zoom)			**intensive (4 day block) small group facilitated on Zoom(S)**
Small Group Support Contact (email)			**(A)**
Practical assessments			**practical portfolio e-submission and e-marking at the end of the trimester**
Scientific Report – e-submission	e-submission and e-marking	e-submission and e-marking	e-submission and e-marking
Topic e-quizzes (x4)	e-submission and e-marking	e-submission and e-marking	e-submission and e-marking
Practical assessment	4x Lab classes (S)	4x Lab assessments during Intensive (S)	**All Lab classes formative feedback and end of unit e-submission and e-marking**
Invigilated exam	F2F - on-campus	F2F - remote options (fixed time)	**invigilated online exam (24 hour time slot) e- marking**

During 2020, all practical classes were cancelled from week 3 of the autumn trimester, by which time on-campus students had only completed 1 or 2 of the 9 mandatory practicals and tutorial classes. On the initial imposition of the COVID lockdowns, many students returned home immediately, and had only completed the second practical session. As part of the emergency response, all lectures and workshops were to only be delivered in an online asynchronous mode, and pending F2F practical and tutorial sessions and intensive school scheduled for week 6 were cancelled. Over the following three weeks the Biology 1 teaching team converted the 9 practical sessions to video and quiz-based activities on the LMS or into an interactive animated laboratory using Adobe Captivate (Adobe, USA, 2019). The latter was linked into the existing LMS. The original on-campus cohorts were offered weekly Q&A drop-ins with topic lecturers, completion of the virtual laboratory sessions and mandatory online tutorials and the off-campus students were offered the option of completing online synchronous activities and the virtual laboratory sessions as a four-day virtual intensive school.

The practical material was either, constructed as a Moodle lesson with kitchen science or software-based activities, or as an interactive format through Adobe Captivate. The key concepts and the tools used for the conversion of the practicals to virtual laboratory lessons are presented in Table II. A forum was set up specifically for discussing the virtual laboratory material. Each virtual practical session had an associated fillable worksheet, pdf files, for submission. These worksheets were originally made as a fillable pdf template, but due to ongoing issues with students submitting blank worksheets, Microsoft Word versions were also provided. Students also had difficulty embedding images into these worksheets. An instructional video was made to demonstrate this process.

TABLE II. KEY CONCEPTS, TOOLS AND METHODS USED FOR THE CONVERSION OF PRACTICAL CLASSES IN FOUNDATION BIOLOGY UNITS (A. BIOLOGY 1; B. BIOLOGY 2) TO VIRTUAL LABORATORY LESSONS. DEFICIENCIES IN EACH APPROACH ARE SUMMARISED FOR EACH VIRTUAL LABORATORY CONVERSION

	Key concepts	Tool used	Video	Static images and text	Interactive animations	Pre-existing software	Science at home	Self-paced quiz	Deficiencies in Online format
				BIOLOGY 1					
Virtual Lab 1: Introduction to Microscopes and Cells	• Stereo and compound microscopes and importance of magnification, resolution, contrast, field of view, depth of field and object size. • Making a wet mount for microscopic observations. • Similarities and differences in structure between animal and plant cells. • Biological cell drawings.	LMS based activity	*	*				*	• Lab safety • Microscopy skills • Slide preparation
Virtual Lab 2: Bacteria, Algae, Protists and Fungi	• Diversity of microbial morphology and activity. • Characteristic features of bacteria, protists and fungi. • Economic, social and medical significance of microorganisms.	LMS based activity	*	*				*	• Lab safety • Microscopy skills • Slide preparation
Virtual Lab 3: Molecular Biology	• Use of automatic pipette to accurately dispense small volumes of liquids. • Processes associated with genetic engineering (restriction digestion, ligation and bacterial cell transformation).	Adobe Captivate animation , Kitchen Science Lab kit	*	*	*		*		• Lab safety • Following protocols • Laboratory skills and use of lab equipment (e.g. use of automatic pipette and a centrifuge, electrophoresis).
Virtual Labs 4&5: Genetics	• Monohybrid and dihybrid genetic crosses. • Mendelian genetic inheritance patterns. • Non-Mendelian genetic inheritance patterns (i.e. genetic linkage). • Genetic test crosses to define an unknown genotype.	Pre-existing computer simulation	*	*	*	* *Drosophi Lab*			• Students struggling with concepts without the synchronous feedback from teaching staff. • Technical issues.
Virtual lab 6: Biochemistry	• Scientific method principle and design an experiment to test a hypothesis. • Flow of electrons resulting from the oxidising substrates. • Flow of electrons in chloroplasts, and role of light in electron flow. • Setting up biochemical reactions.	Adobe Captivate animation		*	*				• Pipetting skills • Following procedures • Transfer and preparation of sub-cellular material • Collaboration skills.
Virtual Lab 7: Energy and ATP	• Explain how ATP is produced during the metabolism of food. • Estimate the ATP requirement of exercise and the ATP yield of food.	Kitchen science and data manipulation					*		• Synchronous feedback during calculations. • Comparative analysis with peers.
Virtual Lab 8: From Cell to Organ Systems.	• Concepts of tissues, organs and an organ systems in animals. • Relationship between structure and function at different levels of organization. • Circulatory, digestive and nervous systems. • Body plan and general layout of internal organs in a vertebrate.	LMS based activity	*	*		* *Froguts (Bio-eLearning Co)*		*	• Dissection and handling of biological material. • Collaborative skills. • Ethics with using animal material.
Virtual lab 9: Coordination, Communication and Movement	• Observing animal behaviour. • Major regions of the mammalian brain. • Neuron and synapse structure. • Structure and properties of bone and muscle tissues. • Musculoskeletal system to move the vertebrate body.	LMS based activity	*	*		* *Froguts (Bio-eLearning Co)*		*	• Dissection and handling of biological material. • Microscopy skills. • Collaborative skills.

	Key concepts	Tool used	Video	Static images and text	Interactive animations	Pre-existing software	Science at home	Self-paced quiz	Deficiencies in online format
BIOLOGY 2									
Virtual Lab 1 : Evolution - Journey to the Galapagos	• Theory of evolution by natural selection and its key concepts: adaptation to environment, descent with modification, and reproductive fitness. • Concept of biological species. • Allopatric and sympatric speciation processes.	Pre-existing simulation			*				This activity was previously an online activity with asynchronous feedbacks.
Virtual Lab 2: Biological Drawing and Microscope	• Drawing for biological learning. • Enhance observational skills. • Procedures for use of the stereo and compound microscope. • Making a wet mount for microscopic observations.	LMS based activity	*	*				*	• Lab safety • Microscopy skills • Slide preparation
Virtual Lab 3: Development and Introduction to Animal Diversity	• Major events of animal embryo development. • Radial and bilateral symmetry. • Body plans. • Phylum Cnidaria and classes.	LMS based activity	*	*				*	• Handling of biological material. • Collaborative skills.
Virtual Lab 4: Animal Development of Body Cavities	• Phyla Platyhelminthes, Nematoda and Annelida and classes. • Evolutionary trends linked to cephalisation, musculature and nervous system. • Body cavity and differences between acoelomate, pseudocoelomate and coelomate animals.	LMS based activity	*	*				*	• Dissection and handling of biological material. • Collaborative skills.
Virtual Lab 5: Sell me an animal phylum – Protostomes and Deuterostomes	• Protostome and deuterostome animal groups. • Challenges with locomotion on water and/or land. • Compare and contrast exoskeletons and endoskeletons. • Adaptation of structures to functions in different groups. • Communicate evolutionary trends and relationships within phyla.	LMS based activity and Zoom presentation	*	*				*	• Handling of biological material. • Collaborative skills. • F2F live pair presentation. Instead, student presented individually on Zoom, to members of the tutorial groups.
Virtual Lab 6: Plant Diversity – From Water to Land	• Distinction between plants and alga and the challenges of living on land. • Diversity in the plant kingdom and major lineages of extant plants • Alternation of generations and life cycle of different lineages.	LMS based activity and backyard science	*	*			*	*	• Microscopy skills • Dissection and handling of biological material. • Collaborative skills.
Virtual Lab 7: Plant Structure and Function – Roots and Stems	• Structure of plant root and stem tissues. • Differences between eudicot and monocot roots and stems. • Differences between primary and secondary stem growth in eudicots.	LMS based activity	*	*				*	• Microsopy skills • Slide preparation
Virtual Lab 8: Plant Parts and Processes – Photosynthesis	• Anatomy of monocot and eudicot leaves. • Different cell and tissue types in leaves and understand how the structure is related to its function. • External environmental stimuli effect, either a temporary or permanent plant response through collation and analysis of biological data. • The effect of environment on photosynthesis at the level of the organism.	LMS based activity and backyard science	*	*			*	*	• Experimental design, and hypothesis testing. • Handling of biological material. • Collaborative skills. • Collation and analysis of data was limited.
Virtual Lab 9: Angiosperm Reproduction	• Flower parts and functions. • Pollination and seed dispersal mechanisms • Formation of the male (pollen) and female (embryo sac) gametophyte and double fertilisation. • Fruit and seed development and relationship between fruit and seed.	LMS based activity and kitchen science	*	*			*	*	• Collaborative skills. • Synchronous feedback.
Virtual Lab 10: Scale in ecology: individuals to ecosystems	The original practical was a field study this was modified into a natural history note study during 2020. The remaining objective was to understand that individuals of a species are grouped into populations; that populations of different species interact to form communities, and that communities are grouped to form ecosystems.	Backyard science	*				*		• Field skills including observation and recording of characteristics of plant populations; techniques of working in study plots, measuring abiotic environmental factors.

The main skills lacking for students in this fully online mode were hands-on experiences with microscopes, microscopy techniques and handling and dissection of biological materials. The magnitude of working with a range of biological scales from sub-cellular to unicellular and organ systems within whole organisms was not tangibly experienced across the unit. Standard lab safety requirements and procedures for working with biohazards, and ethical aspects of working with living organisms were also absent in the virtual scenarios. Specific laboratory practices to labs 4 & 6, such as pipetting skills, following procedures, and transfer and preparation of sub-cellular material could not be experienced. Further, for all activities the collaborative opportunities of working with peers in a scientific setting and synchronous feedback were absent.

During the transition to fully online learning during Biology 1, it quickly became apparent that IT literacy was an issue for many students from both school leavers and mature cohorts. IT issues quickly became evident as a stumbling block and caused further issues in engagement and timely completion of the virtual learning activities. As a result, a key role of the teaching staff during trimester 1 was as IT consultants. This was particularly apparent for virtual lab 5 on genetics, which was a pre-existing free online simulation (DrosophiLab, www.drosophilab.com) that was previously presented with small group learning support within the laboratory to provide synchronous content and technical help. Online learning students require some basic hardware capabilities and software for study and all students ought to have been familiar with the LMS, Moodle, as part of their university orientation (e.g. for submission of assignments electronically) which also required download and competence with standard office software (e.g. Microsoft, Word, Excel, and using HTML5-based web pages). Further, online supervised examinations required video and screen-sharing software. Variations for software and download processes between PC and Macintosh users also created difficulties and specific instructions for Mac users were required. Therefore, to facilitate online learning by students, e-learning resources should be deployed as HTML5 webpages thereby potentially maximising student comprehension of course-specific concepts whilst minimising platform-specific IT issues which distracted them away from their studies. As part of the unit assessment activities, students were required to actively post in discussion forums in Moodle including Zoom chat and breakout rooms. Online etiquette was also poor in some students, and clear guidelines, as to appropriate online behaviour, were reiterated and explained clearly in terms of the university's student code of conduct policy.

Despite clear benefits to an increasing flexibility in learning schedule and location by moving to a fully online program, both poor self-efficacy and self-directed learning were evident through a lack of engagement by many students. This was prevalent in the original on-campus cohort. These students had an abrupt separation from social groups and learning networks that were beginning to form though college and local groups. This was likely to be exacerbated for those students who had their transition to a tertiary setting at the beginning of 2020 without any prior experience of learning in an unfamiliar environment. There were conflicting benefits and disadvantages for students returning home from residential colleges, or from the university town. Many students who returned home to remote and rural areas, also took on more employment than they would have engaged if on-campus. For many of the younger students, this became disruptive to an effective study schedule. Conversely, due to widespread lock down situations, and lack of peer interactions, some students benefited from the lack of distractions of new college life. For the predominantly mature cohort of originally off-campus students, they were provisioned with additional and more structured online learning opportunities than they were previously provided. For example, regular opportunities for synchronous tutorials and drop-in sessions with teaching staff were available to students and provided a unique opportunity to collaborate with peers.

A lack of engagement was apparent through low discussion and verbal interaction during the online zoom sessions; online fora were frequented by about 10% of the overall class; and attendance at the non- mandatory drop in Q&A's with the topic lecturers was mostly below 5 students per duplicate session. When working with students F2F in the laboratory, most teaching staff and teaching assistants find it easier to address lack of engagement. The physical space and direct contacts with peers enhance discussions. Off-campus students usually have limited opportunity for engagement and do not expect synchronous engagement except during the F2F intensive school.

One major issue was the time management for each of the virtual practical classes. Although designed to represent the equivalent 2 hours of the F2F sessions, many students found themselves taking many more hours to complete the tasks. Although the tasks were allocated a specific time, without synchronous and explicit guidance, some on-campus students struggled to prioritise the dominance of each activity and complained that they spent many hours completing a virtual lab. In contrast, other students skimmed over content. This minimal engagement only resulted with students possessing a rudimentary understanding of the content contained within the virtual lab e-resources.

Within the small group synchronous tutorial classes there were a mix of students from the on- and off-campus cohorts with different learning experiences. Due to the changing home situation for many students, (e.g., work schedules, home care of children) they enrolled in random tutorial session to fit their schedule on a weekly basis. In this way, students interacted with different peers and tutors for each session and some students voiced frustrations with lack of organisation and discussion by their fellow students.

C. Considered Response in Biology 2 (Trimester 2– July to October, 2020)

Due to the continuation of government and institutional restrictions from COVID-19, the majority of courses delivered by the institution persisted fully online for trimester 2 (July to October). The decision was made in April to cancel all intensive schools which required interstate travel by many students. The cancellation of F2F classes for all but units which were required for accredited courses was decided at the end of May. Conversion of all practical and tutorials for Biology 2 to an online format was made with consideration of issues presented in trimester 1 for Biology 1. Specific aspects of the unit structure and delivery that were re-considered included: prioritising content, improving online communication networks with both teaching staff and peers, and enhancing opportunities for engagement.

To address the primary concerns in IT literacy observed in trimester 1, an IT Bootcamp was created for all students enrolled in all undergraduate science and agriculture courses to be completed by the end of the first week of trimester 2. This was not a mandated activity but highly encouraged for all; especially for first year students, those who had any issues in trimester 1, and for students who were newly enrolled in trimester 2.

The IT bootcamp was a self-paced and self-assessed online module to provide tips and direction for the IT framework and material needed for success in trimester 2. This online module showcased the basic hardware capabilities and software required for study. Although all students had previously been provided guidance for use of the standard LMS on enrolment, a highly accessible and more detailed version was provided here. Additional instruction was given on software, and for participation in virtual chats, discussions and tutorials. Further, as part of the unit assessment activities, students were required to actively post in discussion forums in the LMS (including Zoom chat and breakout rooms). The software and other competencies for engagement in the virtual laboratories and practicals was provided and guides to platforms other than the standard LMS were showcased. Details on the processes required for assessment submission and online examinations were presented. Finally, clear guidelines and examples of appropriate code of conduct for online activities and social media use were also showcased. Due to the increase in email and forum-based communication for fully online learning, effective strategies for communication with staff were also conveyed.

D. Biology 2: Strategies to Improve Student Success and Engagement

In a typical year, Biology 2 is offered during the winter/spring (July – October) and summer (November – February) trimesters, with on-campus mode only in the former. Typically, on-campus students have three weekly lectures and 10×3 hour laboratory classes with embedded tutorials scheduled over the trimester. Similar to Biology 1, off-campus students would attend a 4 day on-campus intensive school for the practical and F2F activities mid-way through trimester around week 6.

During 2020, continuation of all lectures and workshops were to be delivered in an online asynchronous mode, and F2F practical and tutorial sessions and the Intensive school scheduled for week 6 were re-designed online. The first practical session on evolution which was previously online remained. The remaining nine practical sessions were converted to either video and quiz-based activities on the LMS and/or incorporated activities for plant dissection, identification and ecology in a local garden or neighbouring environment. In contrast to Biology 1, one focus of Biology 2 is the diversity of plants and animals, so students were encouraged to participate in exploration and identification activities in local surrounds using smart phone photography and the LMS fora to share findings. The learning outcomes and the tools used for the conversion of the practicals to virtual laboratory lessons are presented in Table 2b. To improve flexibility for asynchronous activities for Biology 2 online, we had the opportunity for formative submission for feedback in week 7, and summative submission of all practical worksheets at the end of trimester.

To improve organisation, and resourcing of teaching support staff, all originally on-campus and off-campus students were offered the option of completing online synchronous activities (Q&A drop-ins with topic lecturers and mandatory tutorials) either weekly, or as a 4 day virtual intensive school. Two-thirds of all enrolled students opted for the weekly option. As a strategy to improve engagement and peer support, students signed up to a chosen time for the tutorial sessions and remained with the same peer group and tutor throughout the trimester. Engagement in tutorials was enhanced by allocating a mark to each session for preparation of tutorial answers and discussion during each Zoom session. This was given as a nominal mark of zero or one at the tutor's discretion for each of nine sessions and formed 5% of the overall unit grade. A further initiative to improve response time for student enquiries, was that each tutor had an allocated group of students (2 to 3 tutorial groups ~ 50 students) to provide a first port-of-call for administrative feedback and support in a timelier manner than available from the unit coordinator for the class as a whole. The synchronous small group tutorial sessions were particularly valued by the students and many students voiced satisfaction with the tutor support role.

It was apparent that students were more discouraged by the lack of laboratory and F2F opportunities in trimester 2 than they had been during the crisis response in trimester 1. Although students were mostly positive about the activities represented on-line, they wished for real time F2F interactions. Similar to Biology 1, and without timely guidance, many students found themselves taking many hours to complete the '2 hour' virtual laboratory tasks.

VII. Reflections and Prospectus for Future Blended Learning

During 2020, we tended to use a 'more of the same' design approach due to time constraints. Future innovations for blended learning, however, require inherent properties and capacity of technologies to support aligned learning tasks [7]. For blended learning delivery there needs to be careful prioritisation and consideration of the benefits for F2F interactions to fully deliver learning outcomes in STEM [22]. STEM educators particularly need to reconcile active learning as a dominant learning mode for evidence-based instruction practices as institutions move into a greater online space, [42], [43]. The experience of moving fully online during the COVID pandemic in 2020, has enhanced our insights of both methods and modes in the future use of virtual technology in traditionally F2F learning spaces for STEM education. Online learning components have clearly been demonstrated to have advantages, with student choice of time and place being key to a blended learning mode [28], and further for reflective participation and deep learning as students have more time to consider and reflect on concepts [44]. Although many practical skills are best achieved F2F and in a specific learning context, there are opportunities to expand options for both supplementary and primary learning of practical skills. As showcased in the biological sciences during the crisis response, and transition to a fully online mode, the reality of immediate and embodied impact of handling specimens and live organisms or the preparation of lab specimens cannot be experienced in virtual labs [36]. The inclusion of F2F sessions with online lessons clearly has benefits for both content learning and provides students with an opportunity for students to communicate directly with faculty and to receive immediate support and guidance in context [45].

Engagement in the fully online learning setting was clearly an issue for students from both on- and off-campus backgrounds. Even with a more considered response in Biology 2 in trimester 2, motivation for collaborative learning was low amongst many students. Consistent synchronous peer learning groups with an assessed component assisted this, but the self- directed non-assessable learning activities were poorly attended. To improve motivation and thus engagement, there is a need to create opportunities for quick wins early on and reward collaborative behaviours. For future online synchronous activities, we need to assist in more collaborative activities, and solicit both instructor, peer and student led feedback.

The use of LMS is widespread in higher education institutions, and our experience in 2020 has accelerated the use of this tool further than providing an integrated platform to present resources and facilitate administration, to one that facilitates communication and expands the realm of interactive learning [46]. For distance learners of the future, innovations during 2020 will enhance opportunities for better learning interaction with teaching staff and students. New approaches provide students with a more effective learning environment whereby they can have both flexibility, strong interactions and learning support [47].

Both virtual laboratory tools and traditional hands-on laboratories have benefits and limitations when used in isolation. The greater the online support the better we enrich the quality of F2F opportunities to focus on skills through the immediate experience and the sensory impact of handling materials and specimens for competency of practical outcomes. Furthermore, there are clear benefits to provide digital literacy as an inherent requirement for a future STEM workforce in which scientific information is readily available online. Graduates in STEM disciplines increasingly require the ability to acquire, interpret and apply scientific knowledge. Imminent, authentic scientific practice will be via online collaborations and collation of distributed datasets and there are also cognitive benefits to working with both simulated and actual realities for scientific understanding [48]. A combination of traditional or virtual laboratories plays a critical role in this learning, and the future workforce requires experience of the potential and the limitations of simulations as a key tool for emergent knowledge of the world [49].

VIII. Conclusion

The rapid transfer to fully online teaching during 2020 required development of fully online communication channels and new strategies to teach traditionally practical based skills to undergraduate students using e-technology. From an institution with existing competency in blended mode delivery, we have highlighted some of the pitfalls and benefits in the transition of blended learning into online only delivery for introductory biology units. Changing both educator and student perceptions on how practical skills are taught will provide challenges regarding the effectiveness and realism of virtual labs and with student engagement during change. From our experience we can evolve how we teach practical skills content in STEM and provide support for students to moderate their expectations regarding possibilities for learning. Our future students need guidance to move into an online dominated space for collaborative and peer assisted learning, and to fully participate in active, enquiry-based learning [34]. Thus, future considerations to mitigate uncertainty about developing STEM courses for teaching undergraduate students in a virtual learning environment may include:

- Assembly of a multidisciplinary team composed of subject matter experts partnering with learning designers and developers (Risk: requires a significant time investment by the team) or,
- Modify pre-existing 3rd party providers of virtual STEM simulations or interactive lessons (Risk: minimal time investment offset by high upfront and continuing financial investment by the university).
- Establish methods for frequent and effective bidirectional dialogue with students.
- Encourage students to provide critical feedback about the deployed online learning resources.
- Reflect on the both the teaching staff and student feedback to iteratively tailor online learning resources to improve student learning outcomes.

To mitigate uneasiness or uncertainty about teaching and learning in a virtual learning space, we need to have open discussions and share innovations whereby creating strong principles to assess and improve design and methods for online communication. The importance of such a reflection about the design and delivery of STEM courses in online learning provides a catalyst for educational change towards more flexible models and practices in future interconnected learning environments.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

AB, LL and NA were involved in the rapid re development and delivery of the Biology online units reviewed in the transcript. AB wrote the paper; LL and NA contributed to the case study; all authors had approved the final version.

Acknowledgment

The authors wish to thank the unit coordinator for Biology 1, Dr Heather Nonhebel, and the topic lecturers for both Biology 1 and Biology 2: Associate Professor David Backhouse; Dr Tommy Leung, Dr Rose Andrew and Dr Manu Saunders for their contributions to the rapid redesign of the units during 2020.

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