Chapter 9
Digital Wet Laboratories: Transforming Biological Science with Engaging Blended Learning and Online Support

Danilla Grando and David Santandreu Calonge

Abstract University science graduates face unprecedented technological and environmental challenges and are frequently distracted by multiple priorities. To ensure that they can meet current and future workforce needs and have seasoned problem-solving skills, academic staff need to incorporate reality-based learning into courses to engage them in and outside the classroom. A blended learning approach using situated learning was therefore adopted to redesign the curriculum of cell, plant and microbiology courses in a first-year science programme in the School of Applied Sciences at RMIT University (Australia). The new curriculum included (1) constructively aligned online pre-practical class activities and (2) electronic resource packages which enable students to (a) self-help during practical classes and (b) electronically record results of experiments to enable faster assessment and feedback by teaching staff. Some of the lecture content was moved online and this led to a one-third reduction of lecture hours for introductory microbiology. Staff focus groups were held and student perceptions of the new learning environment were evaluated by survey. The findings indicated that (a) gains were related to the engagement of students in higher levels of cognitive processing especially the investigative analyses in real-life scenarios, (b) there was a significant increase in the overall teaching quality scores and (c) there was an increase in achievement of learning outcomes as well as student/staff engagement and satisfaction. In conclusion, digital wet laboratories enabled efficiencies and heightened motivation for both staff and students and mandated the development of many online resources that could be used both in and outside of the face-to-face learning environment.

D. Grando (✉)
School of Applied Sciences, RMIT University, 124 La Trobe Street,
Melbourne, VIC 3000, Australia
e-mail: danilla.grando@rmit.edu.au

D.S. Calonge
RMIT University, SEH Building 14, Level 12, PO Box 124,
Melbourne, VIC 3000, Australia
e-mail: dsantandreu@yahoo.com

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9.1 Introduction

Technological transformation is 'reshaping the fundamentals of how human beings from every corner of the globe communicate, interact, conduct their business, and simply live their lives from day to day' (Moe & Chubb, 2009, p. xi).

The world is changing at an unprecedented pace and so we must reimagine science education to suit today's world. This was one of the principal outcomes of the 2006 Australian Council for Education Research (ACER) conference called 'Boosting Science Learning' which was reviewed by Tytler (2007). The conference was organised in response to several government reports and papers (Logan & Skamp, 2008; Lyons, 2006; Tytler, 2007) that highlighted the mind-boggling problem of falling participation in science courses (particularly physical sciences) in the later years of secondary and also in tertiary education (Johnstone, 2012). In the forward to Tytler's report, Dr Jim Peacock (former Australian Chief Scientist) writes that he believes there are important considerations to be taken into account when reimagining science education:

- Science education should be discovery based in order to generate 'the spark of excitement'.
- Tasks should be relevant to the world around students.
- The teacher's confidence is as important as the materials used.
- Activities need to encourage collaboration just like real-world science.

Some even go as far as to say that the entire old model of higher education has reached a tipping point, is obsolete and facing a complete meltdown (Cuban, 2012) and needs to be disrupted to avoid total calcification. They call for transformation and a disruptive innovation model (Bower & Christensen, 1995; Bush & Hunt, 2011; Christensen & Eyring, 2011). These calls are often confirmed by alarming high university drop-out rates (Bowen, Chingos, & McPherson, 2009), soaring loan debt (Martin, 2012), return on investment of education data (Lavelle, 2012; Pew Research Centre, 2012) as well as higher than ever unemployment figures for university graduates (Yen, 2012), not mentioning the inevitable economic impact (Tan, 2012).

More recently, a number of press reports highlight the worrying fact that companies find it overall very difficult to hire *ready to work* skilled employees (Arum & Roksa, 2010) particularly in STEM (Science, Technology, Engineering, and Mathematics) disciplines (Koebler, 2012).

There has been an explosion of science knowledge with new advances in molecular biology and materials science. There has also been in the last decade a rapid development of innovative, collaborative and engaging online teaching technologies. Longitudinal studies of the effectiveness of these new delivery methods and platforms seem to show that (1) learning is taking place and (2) essentially the same results are produced as face-to-face instruction (Bowen, Chingos, Lack, & Nygren, 2012). A meta-analysis published by Shacher and Neumann (2010) reported that their results indicate students taking courses through distance education *outperform their counterparts in traditionally instructed courses*. We cannot continue to expect this generation of hyperconnected and hypermobile students to learn only in a didactic way, and the need to find alternatives to the exclusive face-to-face model is greater than ever. This was recently acknowledged by John Hennessy, President of Stanford University, in an article by Mossberg (2012). We need to provide choice, versatility and abundant hybrid learning scenarios: broadband Internet, smartphones/tablet computers, cloud-based applications, high-speed wireless technologies and interactive online learning platforms. Additionally the web can become a repository for resources and learning aids (Schell & Burns, 2002), for example, Merlot [http://www.merlot.org/merlot/index.htm], that can facilitate skill acquisition in experimental disciplines.

The fundamental question for this chapter is should academics rethink their role and start using new learning and teaching approaches that blend and utilise digital technologies in and out of the classroom? This chapter will discuss how innovative synchronous and asynchronous approaches have been successfully implemented in a biology programme at RMIT University (Australia) to engage students/staff and improve learning outcomes.

9.1.1 Rationale for the Adoption of Blended Learning and Work-Integrated Learning Approaches

Garrison and Kanuka (2004) define blended learning for the purposes of higher education as the blending of Internet technology with face-to-face learning. Garrison and Vaughan (2008) call it a 'thoughtful fusion of face-to-face and online learning experiences' (p. 5). As a test of how blended the learning is, there should be true integration and alignment between these two components (Ginns & Ellis, 2007; Olapiriyakul & Scher, 2006; Vaughan, 2010). When applied to practical laboratory sessions (digital wet laboratories), blended learning is not just an 'add-on' to a laboratory session, but an integral (and most certainly integrative) part of the functioning of, and activities within, the laboratory, much as one would find in industry. Like industry, computers are an integral part of acquiring, analysing, storing data and monitoring quality assurance, and laboratory practicals should, as much as possible, simulate real-world practice (Balamuralithara & Woods, 2009; Feisel & Rosa, 2005). Garrison and Kanuka also describe the 'proven potential to enhance both the effectiveness and efficiency of meaningful learning experiences' (p. 95) of blended learning, as illustrated by the large blended learning initiative launched at the University of Central Florida where '72 % (45,117) of students are enrolled in at least one fully online or blended course' and '87 % of the students are highly satisfied and 81–94 % of students succeed with an A, B, or C in the course' (Swenson & Bauer, 2012; para. 1). One of the strengths of a blended learning approach is 'to use technology to free yourself from the need to "cover" all the content in the classroom, and instead use class time to demonstrate the continued value of direct student to faculty interaction and discussion' (Bowen, 2006). This has been cleverly used in flipped classrooms (Bergmann & Sams, 2012; Houston & Lin, 2012) or in the UCLA's Gel Scramble tool for teaching molecular neurobiology (downloadable for free: https://mdcune.psych.ucla.edu/modules/gel).

The achievable efficiencies also means that the student workstations can be strategically positioned to display learning support materials in a timely manner and much of the assessment and feedback to students associated with the practical exercises can be performed 'just in time'. The original application of Just-in-Time Teaching (Novak, Gavrini, Christian, & Patterson, 1999) included pre-class activities designed to prepare students for instruction and to assess areas needing focused classroom activity. Used in the wet-practical laboratory, contextual resources created for pre-class activities can themselves be an in-class resource and blended into classroom learning and teaching activities (Grando, 2009; Marrs & Novak, 2004).

9.1.1.1 Closing the Gap Between Theoretical Knowledge and Applicability to the Workplace

Transformation of learning experiences when Information and Communication Technologies (ICT) are closely integrated with traditional teaching approaches is well established (Means, Toyama, Murphy, Bakia, & Jones, 2010). Learning spaces in many institutions have been redesigned in order to facilitate access to ICT, yet preserve and even enhance learning opportunities (MIT iCampus, 2007; Tregloan, 2007). ICT enhanced learning includes more challenge-/game-based (Freitas, 2006; Harris & Brophy, 2005; Prensky, 2001), simulation of the workplace environment and experiences (i.e. SciEthics Interactive go.nmc.org/khreb). In other words, learning by *actively* doing (virtually or hands-on, in-class or as an intern → Work-Integrated Learning) is paramount to effective preparation of science students for a natural transition into the workforce (Murday, 2010; National Academy of Engineering and National Research Council, 2012) and to develop students' ability to apply knowledge to real-world situations (Price, 2012). Integration of ICT into wet laboratories is not only timely but necessary given the already strong and growing technology focus of wet laboratories in the real world and in higher education institutions in general.

9.1.1.2 Is It Worth It?

The challenge with the rebuilding of wet laboratory learning spaces so as to take full advantage of the Web 2.0 technologies (in this case an online web-based learning system) is that it can be prohibitively costly, in an era when institutions are looking for ways to control costs and cut spending. However, smart integration of the technology into existing active learning spaces can have gains that mean that 'learning' can move out of the lecture hall and become real engagement (and achievement of intended learning outcomes) while performing realistic practical exercises, even with a large audience (Lloret, Garcia, Bri, & Coll, 2009; Yuretich, Khan, Leckie, & Clement, 2001). So is it really worth it? Absolutely according to a survey in 2012 by the EDUCAUSE Center for Applied Research, nearly 70 % of undergraduates said they learned most in blended learning environments while 54 % of students say they are more actively involved in courses that use technology (Dahlstrom, 2012).

9.1.2 Work-Integrated Learning

Farmer, Lindstaedt, Droschl and Luttenberger (2004) outline the workplace of a knowledge worker as comprising a 'workspace, a knowledge space and a learning space'. When applied to a laboratory simulating the workplace, workspace includes both the bench space and computer, learning space relates to the support for conscious learning, and 'knowledge space represents unconscious learning' (Farmer et al., 2004, p. 4). In our pilot projects for developing learning space components (learning objects), we have drawn carefully on the types of learning support that are created for professional development. The design of these learning objects includes defining the objectives of the learning experience and assessing learning outcomes *from* the experience (Conole, 2008; Conole & Fill, 2005). Along with learning objects relevant to workplace practice, we employ personnel from industry to give a workplace perspective and bring technical expertise. The closer to industry (so that we can simulate the laboratory space → reality-based learning), the greater the potential for unconscious learning (Gorman, Meier, Rawn, & Krummel, 2000; Van Wyk & de Villiers, 2009).

Arnstein, Sigdursson and Franza (2004) note that a physical divide persists between the physical and information spaces of biology wet labs. This issue has been addressed by installing a sophisticated laboratory-integrated computing system called Labscape at the University of Washington, Seattle. Labscape aims to invisibly integrate computing with laboratory equipment such that it can automatically sense the parameters of experiments. Arnstein et al. acknowledge that there may be positive and negative aspects to this level of sophistication. Although the digital wet laboratory at RMIT does not scale these heights of sophistication, we have drawn on the lessons learned with Labscape.

At RMIT University, digital wet laboratories have been adapted to serve the needs of service teaching as well as industry targeted training workshops/updates. Carl Wieman (2008), recipient of the Nobel Prize in physics in 2001 states 'The purpose of science education is no longer simply to train that tiny fraction of the population that will become the next generation of scientists…we need technically literate citizens with complex problem solving skills' (para. 1 & 2). A view shared by Irving Wladawsky-Berger (2012), former vice-president of technical strategy and innovation at IBM, 'STEM literacy is a particularly important subject for CIOs, given their role in leading this broad use of technology across the institution—and the challenge they face filling highly technical jobs at a time when STEM literacy is at a low level' (para. 2). MIT professor Richard Larson (n.d.) points out that 'a person has STEM literacy if she can understand the world around her in a logical way guided by the principals of scientific thought. A STEM-literate person can think for herself. She asks critical questions. She can form hypotheses and seek data to confirm or deny them' (para. 3). Face-to-face practical classes have still been found to be the best way to teach practical skills (Newton & Ellis, 2007), and indeed laboratory skills are a key competency for microbiology students (Merkel, 2012). In order for students to gain introductory skills, our first-year classes in cell, plant and animal biology as well as introductory microbiology include face-to-face practicals to tackle issues, demonstrate and practise techniques and discuss concepts.

9.2 Educational Environment: The Digital Wet Laboratory Project

In 1999, MIT through collaboration with Microsoft Research undertook a large-scale project to revolutionise teaching through the use of ICT (MIT iCampus, 2007). As part of that project, iCampus transformed 'the classroom experience by replacing traditional passive lectures with active learning experiences supported by information technology' (para. 4), reflected in the high quality of the annual innovative student projects (http://icampusprize.mit.edu/). Based on this, the transformation has also been applied to the learning activities in the digital wet laboratories of RMIT University (City Campus and Bundoora Campus) (Grando, 2009; Green et al., 2007; Vardaxis & Grando, 2007) firstly through continued development of electronic learning and teaching resources (such as digitised laboratory images, online microbial identification databases and real-time data acquisition display) and secondarily via deployment of an ICT management system. This ICT management system enabled files to be displayed/distributed and collected to/from student workstations (Fig. 9.1). It also controlled output to wall-mounted plasma screens.

Activities in the refurbished digital wet laboratories at RMIT University included (a) brief elements of lecture presentation, (b) electronic guides and resources, (c) self-directed digital learning, (d) hands-on experience in science, (e) group activities and (f) tutorial. The digital learning support materials such as electronic guides and resources have also been useful to prepare 'asynchronistic-comfortable' students and demonstrators before attending the wet practical classes (Jeschofnig & Jeschofnig, 2011). Use of these activities and electronic resources in concert transforms the wet laboratory into a transformative blended learning experience (Grando, 2009; Green et al., 2007). It has been reported that even when academics do not teach blended or online courses, 40.9 % of them regularly use simulations or videos in their courses (Allen, Seaman, Lederman, & Jaschik, 2012).

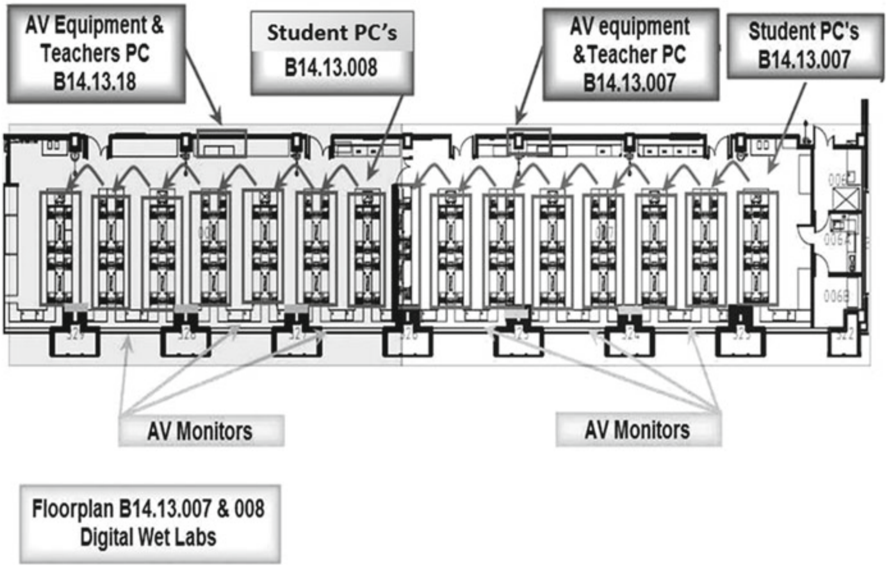

Fig. 9.1 Layout of RMIT city campus digital wet laboratory

MIT iCampus learning activities, as well as those of the tutorial lab at Melbourne University (Tregloan, 2007), are staged in specially designed classrooms designed to maximise student interaction, both with each other and with teaching staff. The building of these learning spaces required costly capital works that is not readily justified within the current competing budget climate facing Australian science schools. Noting that laboratory spaces, in research and industry, retain a linear bench geometry to allow easy access to chemicals and utilities, such a format was retained for the refurbishment of wet digital laboratories at RMIT University.

In order to get students to maximise the use of their time in class, it was decided to rethink the activities that students could participate in. It is known that pre-class preparation promotes participation in the classroom (Santandreu Calonge, Chiu, Thadani, Mark, & Pun, 2011). In the Introduction to Microbiology class, we also wanted students to feel that their classroom exercises mattered so we situated the exercises within relevant case studies. The National Center for Case Study Teaching in Science (NCCSTS) realises the importance of using case studies and has developed a website to showcase science examples (http://libweb1.lib.buffalo.edu/cs/). Since the programme leader had many years working in industry, it was decided to source these case studies from real-world examples. Although the digital wet laboratories project spanned the disciplines of cell, plant and animal biology and microbiology, the amount of blending varied with discipline. We will focus on the discipline of microbiology for this report as this represented the most extensive of the transformations in the curriculum.

9.3 Content

Introductory microbiology at RMIT University is taught in the first year of the Biomedical and Applied Science degrees. In total there are around 500 students spread over 2 campuses. These students have chosen to study towards degrees such as Biomedical Science, Laboratory Medicine, Biology and Biotechnology and Food Science. For some degrees such as Pharmacy and Pharmaceutical Science, it is the only exposure the students will have to practical techniques in microbiology. Previous to the changes made to the course (as shown in Fig. 9.2), the students had 18 h of lectures and 12 h of practical exercises. There was no assessment of skill acquisition other than written exams. For the blended learning approach, the lecture content was reduced by one third by removing topics that could be explored in an alternative way through online learning modules. Lectures were recorded using a personal digital recorder so that students could access the audio recording of each lecture online in the course Blackboard site. The course curriculum changed to include (1) pre-practical preparation, (2) practical exercises rewritten as case studies, (3) mini-introductory talks in the digital wet laboratories and access to student support materials in the digital labs and (4) formative in-practical class assessment of skill acquisition through examining student practical techniques (Froyd, 2008; Garcia, Gasiewski, & Hurtado, 2011; Merkel, 2012; Nielsen, 2011; Smith et al., 2005; Sokoloff, Laws, & Thornton, 2007).

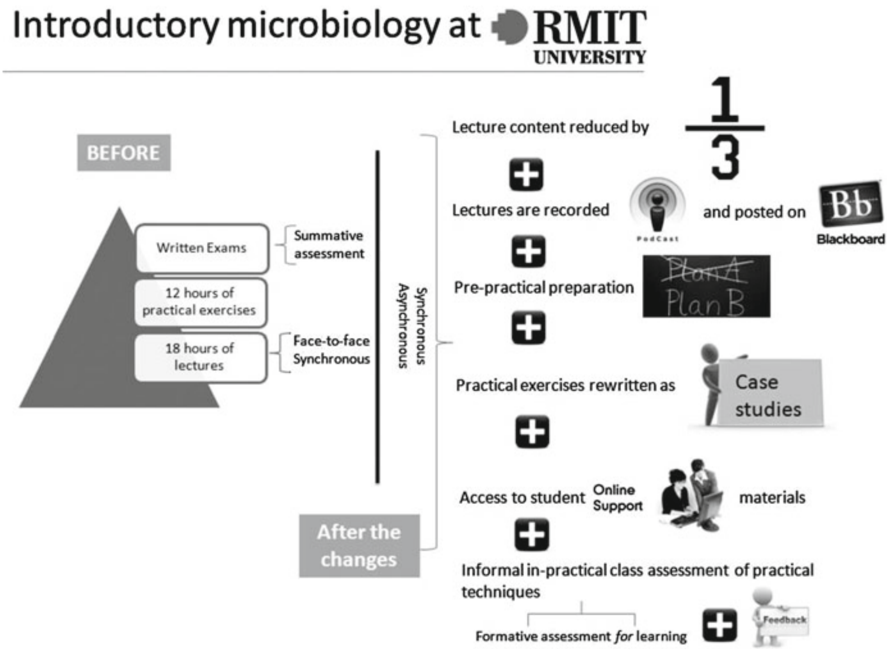

Fig. 9.2 Curriculum before and after the project changes

9.3.1 Pre-practical Preparation

Students were set weekly diagnostic online activities (Riffell & Sibley, 2005), to be performed before each of the first three practical classes (three modules). These modules were worth 10 % of their course mark, and completion of the module was measured through the performance of online tests. Each test consisted of 20 multiple-choice questions and students had to achieve a minimum of 80 % correct on each test to receive the full 10 % of marks. Students could perform these tests unlimited times; however, if they missed a test, they only received two out of a possible ten for each test completed.

The first of the weekly activities consisted of the viewing of three in-house videos produced on safety in the microbiology laboratory. These videos had been produced as part of learning and teaching grant to explore the educational use of video. During semester break, two students who had recently completed the course and had experience with producing 'YouTube' video were paid for 2 weeks to firstly workshop the contents and then act out humorous scenes to illustrate laboratory safety. These videos were then edited and annotated by our staff to produce the safety videos that have been viewed by each cohort of students in the class since 2008. The feedback on these videos from staff and students has been very positive.

The next two weekly activities took the format of what we have called learning PowerPoints (Amare, 2006; Berk, 2011). Each learning PowerPoint would cover either content briefly (already covered in lectures, thus allowing for quick revision) or introduce new content. Students were able to self-check their understanding through questions built into the learning PowerPoints that linked to explanations of the answers (Fig. 9.3). At the completion of each of these learning PowerPoints, the students completed the 20 multiple-choice question on line test.

A student commented on the usefulness of the pre-prac learning PowerPoints:

> I found them really helpful. There were some aspects of the prac that I wouldn't have understood if it wasn't for the pre-prac PowerPoint presentations

and

> You know you can find what you're looking for, especially if you have the idea wrong. You thought you have it right, and then you see it in the actual PP, then you go, hey now, I get it, and doing it again reinforces it

Students were also able to review their lecture material on demand by listening to pre-recorded audio, carefully designed with the online listener in mind. This included frequent references to slide numbers and pauses for questions to test the students understanding of the material. A student commented:

> The availability to listen to the audio while working through the notes has made learning this subject far far easier. In fact I have become extremely enthusiastic about the subject and look forward to my study time for the unit each week. Your effort in the unit set-up is appreciated.

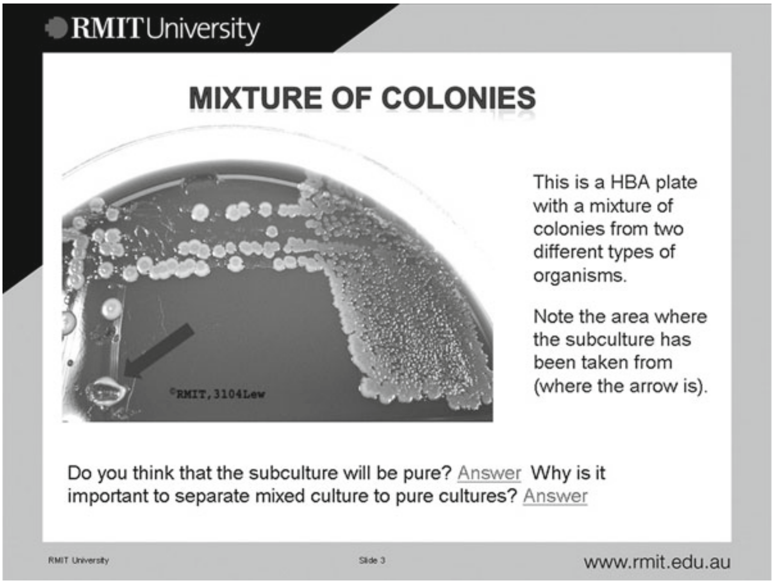

Fig. 9.3 Example slide from a learning PowerPoint exercise

9.3.2 Exercises Converted into Case Studies

As mentioned in the Introduction, it is important to engage students in (1) problem solving and (2) discovery. Making challenging tasks relevant to the world around them is therefore of paramount importance (Kuh, Kinzie, Schuh, & Whitt, 2005). Previously, students were only provided with instructions and recipes in order to practise technique, and assessment tasks focused on this narrow outcome. In the new version of the practical manual, each exercise was prefaced with a description of a case study (inquiry-guided/problem-based learning) to situate the students' learning in a real issue (Lee, 2012; Prince & Felder, 2006). An example of such a case study in shown in the box below:

Case Study to Situate Learning

Analysis No 4: A food manufacturer is concerned that they have had two reports of projectile vomiting in infants following the consumption of infant food cereal. They have sent samples to ACME science for investigation.

Case studies were inspired by real-world examples common to the experience of the teaching staff in order for the instructors to feel confident in helping students understand the importance of performing analyses as accurately as possible. Also, exercises were designed so that the work involved in some analyses is divided amongst a team of two (think-pair-share) and sometimes four students to encourage brainstorming, collaboration and teamwork (Oakley, Felder, Brent, & Elhajj, 2004; Springer, Stanne, & Donovan, 1999).

9.3.3 The Practical Session

As each of the six practical sessions was scheduled for 2 h, it was important that the class was well organised and structured. This was enabled by the format of the digital wet laboratory. To create a digital wet laboratory, an existing practical laboratory was fitted with a student computer at each student workstation (Fig. 9.1). A central teacher station had software installed that (1) enabled content to be streamed or sent to each student computer and (2) have content streamed to a number of plasma screens on the walls around the practical laboratory. Each class began with between 5 and 10 min of material that would have previously been in the lecture, but had now been moved to the relevant practical. This mini-lecture was streamed either to plasma screens or student computers.

Students then had sent to each of their screens an electronic resource pack. This contained resources such as *how to* videos and recipes for techniques that would be used in that class. Each resource pack was tailored for a particular class so that students received a new one for each class. Students would then have a mini demonstration of techniques by their class instructors (one class instructor/12 students).

The remainder of the laboratory time was for students to investigate and report their case findings into laboratory books. As new skills were learned in each class, students were assessed on their skill acquisition. For instance, the first week they learned to use a microscope to investigate a variety of microorganisms. They were taught trouble-shooting techniques in this class. In their second class, students again used a microscope to investigate a new case; however, they were required to show the instructor that they were able to set up the microscope for viewing as the instructor had previously 'meddled' with the microscope set-up! If students did not manage to use the microscope professionally, they received instant feedback and were given an additional opportunity the following week (reflective process) to master the practice (Dunne, 2011; McDonnell, O'Conner, & Seery, 2007). With coaching, each student passed each technique hurdle in the 6 weeks (three assessed technique hurdles). The two remaining assessment tasks were performed during the final sessions, and these were for how students recorded their experimental findings and a 'happy mark'. The happy mark was based on how eagerly they engaged in the collaborative activities (teamwork) and whether they attempted to ask relevant questions. We stressed with students that a positive attitude and good communication skills are vital in the sciences!

In order to keep the sessions running on schedule, a lesson plan was displayed on each of the screens (Fig. 9.4). The electronic resources pack on each student's

Lesson Plan Session 1

• Introduction by Danilla	10 min
• How to use the microscope video	10 min
• Instructor demonstration	20 min
– Safety	
– Using the microscope	
– How to perform hand hygiene prints	
• Ex. 1a S1 – practice setting up mic with prepared smear	
S2 – complete the "What organism am I?" quiz	20 min
• Then swap roles S1 and S2	20 min
• Ex. 1b Plate culture with mystery organism	10 min
• Complete Hand Hygiene Study Part 1a	10 min
• Discussion of your results and answers with demonstrator	15 min

Fig. 9.4 Example of lesson plan to keep students on time

computer means that they could access help when their instructor might be busy helping or assessing a student. A visitor to the digital wet laboratory noted how focused and engaged the students were in their activities compared to other practical classes (reproduced with permission):

> I was impressed with how focused the students were in this class I observed in the digital wet lab (quite different to what I see in my lab classes, though I note it is a different student cohort, so that might make the difference!). I want one! I can't wait until we get a similar lab in my area!

Initially instructors in this class expressed concerns that they would be made redundant through the provision of so much pre-preparation and online resources during the sessions (Redmond & Lock, 2011; Vaughan, 2004). Instead these instructors have commented on how well prepared the students were for class and that the students assimilated the theoretical knowledge well over the short series of sessions.

The students themselves have expressed amazement at their knowledge and skill acquisition over such a short period of time. Students have commented:

> In this particular class the digital learning has been exceptional. Instructions clear, information easy to find and follow and assistance given quickly when assistance required.
>
> I have only experienced advantages in comparison to former lectures conducted at uni. I have accelerated learning, better explanation and tools to complete assessment.
>
> Just a quick email to express mine and my classmates enthusiasm and appreciation of both the GERMM and pre-practical slideshows as used in Microbiology 1 (BIOL2158.) Both of these resources have been invaluable through our studies and practical classes, and no doubt will be for future classes and years.

Importantly more students are expressing an excitement to continue a career in science after their interest has been ignited by the material.

Table 9.1 Learner satisfaction survey (5-point Likert scale; $n = 32$)

Aspect	Response
The role of the digital learning support of my practical classes has been clearly communicated to me	4
I have been provided with constructive feedback in my digital learning support of practical classes	3.9
Digital learning made my practicals more interesting	4
Digital learning helped me with my understanding of my practical classes	4
Digital learning enabled me to prepare for the practical class	4
I have sufficient support to enable me to use the digital learning materials	4
Digital learning helped me identify areas in my learning that required further attention	4
Digital learning demonstrated that I was making progress in my understanding of the practicals	4
Digital learning demonstrated that I was making progress in my understanding of the overall course	4.2
Working with digital learning support enhanced my IT skills	3.5
Digital learning combines well with the learning in the practical laboratory	4.2
The whole digital learning experience was positive	4.5

9.3.4 Digital Wet Laboratory Evaluation

To determine the effectiveness of the blended learning approach to digital wet laboratory learning (DWL), students attending one offering of a DWL practical class in 2008 were surveyed using an online *Learning Experience Questionnaire* designed during the 2007 phase of the project. They were invited to provide responses using a 5-point Likert response scale with point 1 marked ‘strongly disagree’ and point 5 marked ‘strongly agree’ (the three in between points were not marked). At the end of the scale, a point was provided marked ‘don’t know’ and if marked did not form part of the score. Questions about their satisfaction with the technology and learning gains on specific outcomes were also included to help instructors gauge the success of the first offering of this course. Students were invited to stay at the end of class to complete the survey, and the survey was handed out and collected by someone not associated with the teaching of the unit.

9.3.4.1 Findings

Thirty-three students were invited to complete the survey, and 32 completed surveys were returned. Students were not given any incentive to encourage them to participate. The average rating (on 5-point Likert scale; $n = 32$) obtained for each statement is presented in Table 9.1.

Students' ratings suggest that (1) they felt the digital learning approach was particularly engaging and useful, (2) it helped them improve their skills, (3) boosted their motivation and confidence levels as well as (4) self-efficacy. The structured blended approach as well as the alignment with the learning and teaching activities in the practical laboratory was well received, and the way the instructors supported them was useful and strongly appreciated.

Staff were also strongly supportive of the changes (the following comment is from an academic invited to participate in the project):

> Thank you for the opportunity to contribute to this project, and I wish you all the best with your endeavours to get more digital materials up and running. It was a huge success.

Another academic noted that the digital wet laboratory enabled a more integrated approach to discussing experimental data generated by students:

> The groups' results are then entered into the main lab computer to be shared with the rest of the class. The results from the whole class are displayed resulting in a discussion of the variety of data collected. The overall results are then sent to all students for their reports

It was interesting to note that students are still attempting to print out all the resources. For instance, students commented that there was 'too much to print out'. Over time we have seen less students coming to class with printouts due to the ready access to online access to the material. A teacher commented:

> Most students access their prac lab notes via the lab computers rather than printing them out

In one laboratory where computers were retrofitted, bench space was reduced due to keyboards. A student commented:

> Not enough bench space to keep things aside. Digital is really great, however bench space could be maximised

It is hoped with the introduction of touch screen technology will reduce the problem of situating keyboards amongst experimental material.

9.4 Discussion

9.4.1 Digital Wet Laboratory Challenges and the Way Forward

Combining digital with experimentation is not new to the workplace, increasingly science professions rely on real-time computer-based acquisition and analysis of experimental data (Fig. 9.5). This presents many challenges for tertiary institutions as the laboratory environment in science may use hazardous chemicals and Bunsen burners. In industry, laboratories overcome this by using electronic versions of burners and fume hoods for working with chemicals.

An additional challenge was justifying the cost of fitting out existing laboratories with computers. In 2007 a project grant was received to transform the existing city campus laboratory into a digital wet laboratory. By comparing the results of quality assurance questionnaires (Table 9. 2) distributed to students that give a good teaching

Fig. 9.5 Student and teacher discussing experimental results with the aid of computer resources in a digital wet laboratory

Table 9.2 Good teaching scores (GTS) comparing those in the digital lab (city) to the Bundoora cohorts

	GTS 2007 (%) predigital lab	GTS 2008 (%)	GTS 2009 (%)
BIOL 2256 (city cohort, digital lab 2008)	53	75 post-digital lab	70[a]
BIOL 2257 (Bundoora cohort, no digital lab until 2009)	57	53	60 post-digital lab

The GTS is calculated by adding the number of students in a course that 'agree' or 'strongly agree' with good teaching items on a questionnaire as a percentage of all student responses, so the GTS ranges from a low of 0 to 100 %

[a]Students commented on slow and unresponsive computers. Requests were made to the Information Technologies Department to address this issue

score (GTS) for each course, we were able to argue that students at the Bundoora campus (Melbourne, Australia) were disadvantaged by not having access to computer resources during their practical classes. We also have students who travel from remote parts of Australia to undertake laboratory classes, and these students may not be able to afford or have access to computers. This argument was successful and a practical laboratory at Bundoora was also transformed into digital wet laboratory for 2009.

It is interesting to note that in 2009, when the Bundoora cohort first performed their practical classes in DWL, the GTS result did not rise as markedly as the City cohort had in 2008. The Bundoora students may have been influenced by the fact that the School of Medical Sciences had implemented DWL in other laboratory medicine classes in 2006. There may have been a lack of ‘wow’ factor in this group of students who had already experienced DWL in other classes. It is interesting that one Bundoora student commented:

> Why haven’t we had this a long time ago, I mean we have computers for everything else, why can’t we have them in the labs?

A limitation of the evaluation performed on this project could raise the question ‘Are the students’ learning less now?’ Students are required to demonstrate technical capability development through assessment of their performance of techniques. In fact the ready access to resources helps them practise in class before assessment. The curriculum is also reviewed by a programme team, and no adverse findings have been reported by those who teach at second-year level. In fact there is anecdotal evidence that students who enter into our university from elsewhere have knowledge ‘gaps’ and lack of technical expertise. To help these students, the digital materials developed for first-year classes have been embedded into the second year as bridging materials, and we have received messages of thanks from those students.

9.4.2 The Paperless Laboratory

During the introduction of digital wet laboratories at RMIT University, other discipline groups such as biology (cell, animal and plant) have been supported with project funds to develop learning resources to be used both in and out of laboratory sessions. The aim of this work was to enable students to progress more efficiently through the practical sessions so that they have more constructive time in class to digitally analyse their findings and compare their results with those of other students and those of previous experiments. Too often students take home the results of practical classes only to flounder in the interpretation of these findings while trying to write up results out of class. On the conversion of practical manuals to digital manuals, a tutor in cell biology commented:

> The digital answer sheets made submission of student work run the smoothest ever. The students really liked them and found them very easy to use. The answer sheets eliminated all need to reiterate over and over what was required for submission.

and

> The updated pracs – with errors removed – also made the ‘pracs’ run much more smoothly and the students were much more positive about their experience than they have been in the past.

and

> Digital access to the lab manuals also allowed us to update anything on the spot rather than thinking of it and then forgetting to do anything about it…. All up it was a great success.

9.4.3 Electronic Marking of Reports

We are currently piloting the use of electronic devices to mark student scientific reports (Berque, Bonebright, & Whitesell, 2004; Derting & Cox, 2008). As many science classes involve the drawing of observations, moves to electronic reporting have been slow. The availability of pen devices can change this, and so in our physics laboratory, electronic tablets and pens have been provided for students to draw their findings. These electronic files can be easily accessed by instructors who also mark up these reports with comments and then send the files back to students. In this pilot trial, the turnaround time for feedback to students was reduced significantly compared to the traditional submission of paper reports. This has also been observed by Santandreu Calonge et al. (2011). A demonstrator noted:

> …because they have to have it done by the end of their session and it has to be marked by the end of their session, so it's really good because I don't leave the class with any homework for me. I don't have to worry about marking them in my own time. It's just done during the session and that's it. So that's really easy.

Tracking of reports was simplified as students could see the status of their reports from anywhere and at any time.

9.4.4 Online Tutorials

In an alternative offering of introductory microbiology for allied health students where it has been requested that separate tutorials be included in the offering, the large numbers of students have led us to trial online tutorials.

Each week 20 questions were placed online in a discussion forum and these explore concepts introduced in lectures. Students were advised that participation in these tutorials is not compulsory; however, participation in these online tutorials will allow a 2 % upgrade if this will result in a higher grade designation such as distinction upgraded to high distinction and fail upgraded to pass. In order to qualify for an upgrade, students must participate twice in any online forum, and they must participate in two of the six online tutorials. Their participation may take the form of addressing the tutorial question in discussion format that helps a reader better understand the concept at the centre of the question or, in reply to an existing discussion, provide new information and alternative explanations that help explore the concept and lead to better understanding.

The tutor participated after the closing time of the tutorial by addressing any discussions that miss the point of the question or to further discuss problems with any discussion threads posted (Flynn, 2012). In our evaluation of participation in these online tutorials, we have found around an 80 % participation rate. The main incentive for participation is that the questions on the summative exam are taken from this pool of online discussion questions!

9.4.5 Electronic Glossaries

Students who progress from this introductory microbiology to the intermediate and advanced level microbiology will be performing a number of advanced tests that require interpretation of results. The recipes for performing these tests and guide to interpretation have always been provided as a separate text that students purchase. Unfortunately many of the tests that the students perform result in the interpretation of colour changes, and the text was produced in black and white to reduce the cost to students.

In 2008 we received project funds to produce a glossary of electronic resources in microbiological methods (GERMM). This project catalogued all tests performed in intermediate and advanced microbiological techniques. Each test description is accompanied by colour photographs of test reactions. Where the name of tests or microorganisms may be difficult for students to pronounce, these words are hyperlinked to an audio file of the pronunciation (Parsons, Reddy, Wood, & Senior, 2009). The tests were arranged alphabetically and are accessed through Blackboard which was accessible during the practical classes or outside of class for student preparation. Students found this resource invaluable as it is easy to navigate and use and has improved their understanding of the tests and terms used in our discipline. Students commented:

> I have only experienced advantages in comparison to former lectures conducted at uni. I have accelerated learning, better explanation, tools to complete assessment

and

> Without the digital learning I probably would have failed!

We are currently exploring how an augmented reality-based learning system could be introduced to help students understand difficult concepts (Maier, Klinker, & Tonnis, 2009) and how learning analytics could help use what is learned to revise curricula, teaching and assessment in real time.

9.4.6 Off-Campus Science Labs

There is abundant evidence that it is possible to teach introductory science labs online to large audiences (Gilman, 2006; Jeschofnig & Jeschofnig, 2011; Smith et al., 2005; Stowe & Lin, 2012; Udovic, Morris, Dickman, Postlethwait, & Wetherwax, 2002). The excellent guide to resources for best practices in teaching lab science courses online by Jeschofnig and Jeschofnig (2011) includes an appendix describing how to place an introductory microbiology class completely online. Northwestern University, with support from the Hewlett-Packard Catalyst Initiative and the National Science Foundation, is also offering a collection of remotely accessible labs with its iLabs network (http://ilabcentral.org/about.php). This addresses one important aspect of such an introductory class in that it can be difficult to staff such large classes with instructors. In the first-year offering of introductory microbiology, there were around 500 students, and with a ratio of one instructor to 12 students, it was challenging to find that number of experienced instructors. This was somewhat alleviated by offering classes at a variety of times; however, instructors are usually not able to take more than three classes.

We would be reluctant to move down the path of simply dispatching instructions for students to perform the exercises at home. A key component of our classes was that the in-class electronic resources have freed time for instructors to watch student technique and give them instantaneous critical and constructive feedback. Also as mentioned at the start of this chapter, it is important that students be exposed to confident experienced instructors and that they have ample opportunities to perform collaborative activities.

9.5 Conclusion

The majority of students today 'think and communicate in fundamentally different ways than any previous generation' (Jukes, McCain, & Crockett, 2011, p. iii) and it is incumbent on academics to engage these digital natives.

The intensive use of digital wet laboratories has enabled teaching staff to reconceptualise their teaching strategies and curriculum such that a constructively aligned blended hybrid lecture/tutorial-laboratory session could be conducted. Theory was supported with online exercises which were immediately followed by the supporting blended practical activities to directly reinforce understanding and promote feedforward (Brinthaupt, Fisher, Gardner, Raffo, & Woodard, 2011). In this format, some lecture material was able to be moved out of the lecture theatre and be delivered in shortened duration or blended with or integrated into laboratory exercises with greater opportunity for students to engage in active learning in the appropriate laboratory context.

We found that (1) academic staff expressed increased levels of motivation and found that they were able to more productively reprioritise their time as deeper learning was obtained during laboratory practical sessions. (2) Students' expressed high level of engagement and enthusiasm during the course as interactions (face-to-face and online) increased exponentially. Learning and teaching approaches in higher education institutions across the globe are indeed changing inexorably and ineluctably: while academics should not really worry about their very adaptive digital resident students (White & Le Cornu, 2011), they should actively brainstorm innovative ways to fully engage them inside and outside the classroom. The launch of MOOCS (massive open online courses) worldwide has in recent years challenged the education sector, and despite resistance and reluctance, new modes of delivery had to be adopted to cater to industry and students' needs. Change is scary but required, and university departments were often dragging their feet (and still are!) before implementing necessary measures to improve learning and teaching practices in their institutions, where the quintessential lecture format is still the norm.

Colleges of sciences in Australia do not always come to mind first as being at the forefront of the educational e-revolution. But it is changing rapidly with, for instance, fully online open courses in microbiology using reality-based learning and online teamwork (Santandreu Calonge & Grando, 2012) to engage nonscience majors.

The preliminary evidence of successful achievement of learning outcomes in the digital wet labs is extremely encouraging and promising, but (1) there are quite a few limitations ('organic growth', limited budget, staff training and turnover, not enough yet statistically relevant student engagement data), and (2) we are still in a trial and error [iterative developmental stage]. We are constantly fine tuning activities and gradually increasing the amount of content and collaborative activities delivered/done online, based on feedback from an expanding base of students and our discussions with colleagues worldwide in our field and others.

Will the course content continue to evolve? Most likely as we will have to adapt to an ever more 'part-time', mobile and computer-savvy audience and thus develop more digital tools to meet the learning needs of our students. Are we thinking of going back to the traditional practice in teaching our microbiology programme? Not a chance.

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