Developing laboratory practicals for the modern curriculum: a place for virtual laboratory sessions

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Abstract

Laboratory practical sessions are often noted as highlights when considering student feedback on the module *LC Clinical Exercise Biochemistry*. Strategies to make content accessible to all students is key, irrespective of educational background or prior lab experience, to enable students to interact and engage with the sessions to achieve the relevant module learning outcomes. Students can often feel anxious or under prepared for such sessions, as the laboratory is often a novel environment and it is not feasible to provide 1-1 support for groups when delivering laboratory classes to 100+ students. Incorporating virtual laboratory sessions may be one method to minimise anxiety and lack of preparation, and to enable students to rehearse in a low-risk environment to prepare for upcoming in-person laboratory practical sessions. This review focuses on learnings from *LC Clinical Exercise Biochemistry*; an undergraduate module delivered in the School of Sport, Exercise and Rehabilitation Sciences at the University of Birmingham and examines existing literature on the value of virtual laboratory applications in teaching. This review helps to inform best practice for maximising the outcomes from undergraduate laboratory practical sessions to ensure equitable student experiences and improved learning outcomes.

Introduction

> "*The laboratory has won its place in school; its introduction has proved successful. It is designed to revolutionize education. Pupils will go out from our laboratories able to see and do*"
>
> Griffin, 1892. (Rosen, 1954)

Laboratory practicals have historically been considered an integral component of university science courses, with the *Commission of Professional Standards and Practices of the National Science Teachers Association* suggesting the inclusion and benefit to students was “too obvious to argue” (Hofstein and Lunetta, 1982, p. 201). Yet, as time has passed, the true value of laboratory practical labs has been questioned, with restricted budgets, time-pressures, increasing student numbers and a lack of empirical data to support claims of revolutionising education. Perhaps though, this is more a reflection of the lack of properly controlled scientific research and differences in interpretation of what a meaningful outcome of a lab practical looks like for students. Are improving grades the only important metric? Or is the opportunity for open-mindedness, curiosity, and creativity of equal importance in enabling students to become the scientist (Hodson, 1993). Although laboratory practicals have long been part of science courses, their integration with rapidly developing technological advancements has not been fully explored. The integration of computer laboratory simulations into student learning platforms is one such example. Whilst it is unlikely that the tactile hands-on experience can be fully recreated in a virtual setting, significant steps are being made towards bridging the gap between physical laboratory space and the virtual world. This is a step progressing at a rapid pace, in part due to the COVID-19 pandemic (Vasiliadou, 2020) and emergence of artificial intelligence (AI). In this review, we aim to make the case that laboratory practical sessions are still an integral component of undergraduate science modules and can be adapted to embrace the technological revolution, through the lens of an existing first-year undergraduate module - *LC Clinical Exercise Biochemistry*. We also discuss the potential utility of virtual, online laboratory simulation to enhance the student experience and learning outcomes.

The laboratory practical in biological sciences: insight from LC Clinical Exercise Biochemistry

LC Clinical Exercise Biochemistry has been a longstanding first year module delivered from the School of Sport Exercise and Rehabilitation Sciences. Formally known as *LC Cell Physiology and Biochemistry,* the module has transitioned to a more applied clinical focus attracting students from a mixed range of educational backgrounds and from a variety of courses from physiotherapy to molecular biology. The overarching aim of the module is to provide a comprehensive introduction to biochemistry and metabolism, with application to clinical populations in both health and disease. In the 2022/23 academic year, 295 students were enrolled, and a key feature of the course has been to provide students with the opportunity to experience a laboratory setting and apply their acquired knowledge from lectures, seminars, and online activities. The laboratory practical was completed in week 5 of the module. Week 4 had a dedicated seminar to the running of the session alongside online Canvas materials, including lab safety and video demonstrations of lab skills. In week 6, informal feedback was collected on how students experienced the laboratory practical during a small group seminar. Key themes identified by several students were that they enjoyed the opportunity to gain hands-on experience in a lab, it was a new experience that they hadn't thought about much before and that for some it brought up some feelings of nervousness as they didn't want to 'mess up' experiments.

Having had the opportunity to engage with students about their experiences, the general feedback suggested that the lab practical was a positive and enjoyable aspect of the module. In fact, there was an indication that utilising a more applied approach to learning was favoured as it avoided the repetition of lectures and seminars. However, some students reported some anxiety towards the laboratory sessions, which was most evident in those not from a biology background in previous education.

How the nature of the subject can influence teaching practice and the use of a laboratory practical session

Students graduating from human biological sciences and related disciplines should be able to demonstrate proficiency in foundational concepts and possess the skills needed to practice as professionals (White *et al.*, 2013). Whilst this is a lofty goal for a single first year module, the very nature of *LC Clinical Exercise Biochemistry* guides students towards this outcome. Foundational or threshold concepts are taught on an almost weekly basis. In week 1, students are taught about elements, molecules and cells - the basic building blocks of human anatomy, before diving into carbohydrate, protein and lipid metabolism in weeks 6, 7 and 8. Each of which, when mastered, can transform a student's grasp of the discipline, yet a lack of understanding can prevent progression into applied settings (Loertscher *et al.*, 2014). Because of this foundational nature, there are a wealth of well-written textbooks that can assist student learning, and many of our teaching materials follow themes presented in them. To acquire skills needed to practise as professionals, it is not sufficient to rely solely on traditional teaching in the module and thus, journal clubs, collaborative student-led sessions, and the laboratory practical feature as key components of the module.

Focusing specifically on the laboratory practical component of *LC Clinical Exercise Biochemistry*, simply giving instructions for students to follow, then expecting positive outcomes and 'accurate' data generation is not appropriate for the level of the course. Instead, providing equal opportunity to students to engage in the practice, and to experience the process of science is key (Brewer and Smith, 2011). Further to this, the class size (300 students) and financial cost of running a practical laboratory means consideration must be given to ensure students are as prepared as possible before entering the lab. This is not only from a skills competency aspect, but more importantly from a health and safety perspective. Therefore, in the lead up to the practical laboratory we have provided theoretical and practical background materials, video demonstrations of key lab components, and interactive demonstrations of key equipment such as pipettes in prior seminars. These methods have been shown to improve student engagement and understanding in practical STEM laboratory sessions (Onyeaka *et al.*, 2023, Lacey and Wall, 2020).

Creating an effective learning environment

"*Learning science means learning to do science*"

(Woodin *et al.*, 2010).

Being a first-year undergraduate module, *LC Clinical Exercise Biochemistry* encompasses significant diversity in relation to student academic backgrounds and experiences. For example, students who joined the module having studied human biology, chemistry or similar subjects are likely to have a better understanding of laboratory skills. For those students studying other subjects, this can create a gap in their experience and how they feel towards the laboratory session. As previously mentioned, practical sessions can evoke anxiety and 'pressure' for students if expectations are not managed prior to the session. Reflecting on how we, as the module team, can improve students' experiences can be assessed in relation to the conceptual framework for course-based undergraduate research experiences (Brownell and Kloser, 2015).

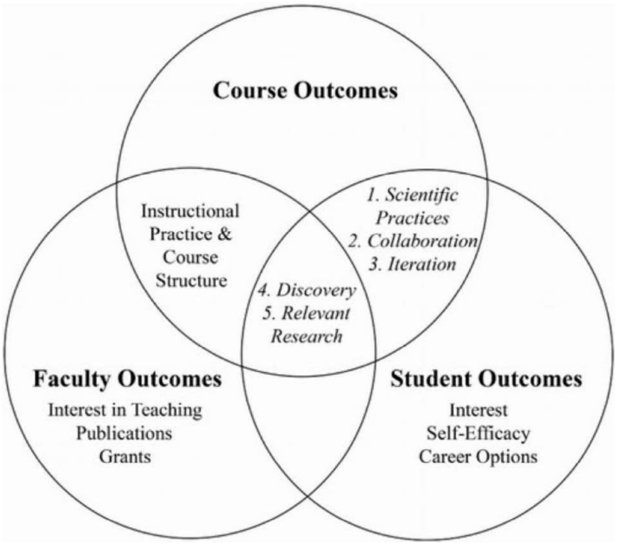

Figure 1. The conceptual framework for course-based undergraduate research experiences can be utilised to critically reflect on the interlinking impact of student outcomes, course outcomes and faculty outcomes on the learning environment created in lab practical sessions (Brownell and Kloser, 2015).

To facilitate the creation of an effective learning environment, it is important to consider what outcomes may be more important for the students (Figure 1). This could range from getting a first taste of what laboratory work is like in practice, to having a hands-on experience of implementing the 'scientific method' and generating real time data. It is also likely that some students will prefer theoretical work, but it is important for them to gain experience and understand the value and importance of laboratory experiments. Whilst developing students' grasp of the scientific method is important, the specific practical skills are only part of the picture. It is important for students "to know disciplinary ideas deeply, know how these ideas are connected and why they are important, and know when, where, and how to use this knowledge to accomplish a task" (Brownell and Kloser, 2015, p. 537). This can be achieved through practical applications of theoretical knowledge. Whilst coursework for this module has been linked to the laboratory practical sessions, the outcome of the session, whether correct data is collected or not, is not assessed. This has created a balance between motivating students to attend and engage with content, without the stress of completing a perfect laboratory experiment on the first attempt. This has helped to remove the 'pressure to perform' for a significant percentage of students and gives a more relaxed setting to reach the main learning objectives of the sessions. One interesting outcome from the module in the past semester (Semester 2, Spring 2023) is that both the laboratory handbook and instructional video achieved similar page views on Canvas, both being amongst the top viewed pages on the module (1500 views each). Having both a visual aid and step-by-step guide was highly valued by students, with several students giving feedback that more opportunity to develop practical skills would be valued.

Challenges faced with laboratory practical sessions

"Science is not a 'rhetoric of conclusions', rather it is a messy, creative, social, iterative and human process"

(Schwab, 1958).

Emphasising the importance of developing student enquiry throughout undergraduate courses is not a new concept. Yet, defining what level of 'enquiry' a student has achieved through assessment, how much of a guiding role a teacher should play in this process, and understanding if there are varying degrees of student enquiry, are all questions that are difficult to answer (Buck *et al.*, 2008). The integration of laboratory practical sessions into biochemistry courses has been one such way to facilitate this process. However, the over-prescribed nature or 'cookbook'-like instructions and focus on getting the 'right' answer can give students the impression that science is a collection of facts that we already know and a set of procedures that we need to follow step by step. Whilst delivery of this module has reinforced the exploratory nature of the practical sessions, on reflection our assessment methods do fall short of capturing students' enquiry and experiences of the sessions.
As an example, one method of evaluating the effectiveness of teaching on *LC Clinical Exercise Biochemistry* has been to collate feedback from academic staff supervising the laboratory practicals on how the session ran? For example, did students complete the objectives in the allocated time? Did students manage to collect the right answers to questions? This of course misses an important aspect of the practical; how did students engage with the course content and was the teaching provided adequate to successfully complete the objectives? Some quantitative insight can be collected from Canvas metrics. In general, students who engage with the course content more frequently achieve better

grades in the practical related coursework, indicating the level of teaching delivered is sufficient to support better student outcomes (Figure 2).

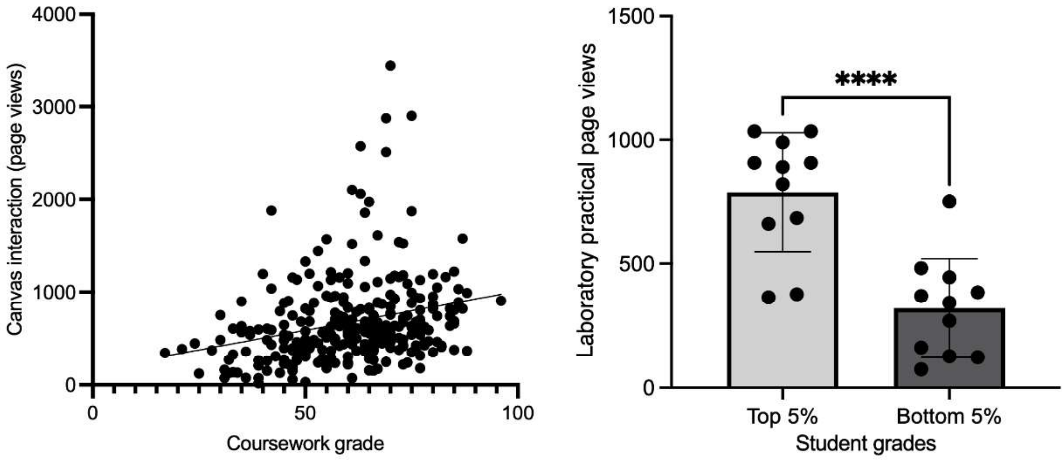

Figure 2. Canvas metrics showing that student engagement with the available taught content across the module is associated with higher grades. A: Overall student engagement with Canvas is significantly associated with grades achieved on lab-practical linked coursework ($R2 = 0.07$, $F(1, 289) = 21.79$, $p < 0.001$). B: Students who achieved grades within the top or bottom 5% for the 2023 academic year had significantly different lab practical manual page views (top 5% = 787.9 ± 240.5, bottom 5% = 320.5 ± 199.8, $P<0.001$).

Yet, the surface level interpretation of this data does little to aid the understanding of why students are not engaging with the course content. In fact, measuring student engagement is an incredibly difficult task when viewed from multiple lenses (Sinatra *et al.*, 2015). Are the teaching methods and pre-laboratory content available allowing all students, from diverse educational backgrounds, to get an equitable experience of the lab? Or will those with a background in biology be at a significant advantage? Are students who feel more confident in the lab to 'experiment' going to have a better experience rather than worrying about failing to get the intended results? Do all students see equal value in laboratory-based skills in relation to a future career? Of course, differences in previous laboratory skills experience are impossible to remove as it is a first-year module, however, thinking about the opportunity students have to develop competency going forward is key. Can we give all students the opportunity to develop competency in a lab setting following the course? This will likely require the provision of suitable practice and opportunity to experience a lab setting more frequently, something that is often limited by the cost, space, and resources for running labs. This is perhaps where we can be aided by the rapid development in technology – the use of virtual laboratory demonstrations.

Laboratory practical sessions in the technological revolution

Practical laboratory demonstrations are a key component of developing the future generation of Biochemical scientists and feature throughout the dimensions of the UKPSF framework listed by the Biochemical Society (Smith, 2022). The idea of virtual laboratory (vLab) demonstration or participation has been considered as a potential tool to enhance student learning for several years. Across the literature, vLabs have been used to describe teaching materials from passive video demonstrations to more active virtual laboratory tasks. Early research into vLab demonstrations has shown that when used as a 'pre-lab', knowledge of, confidence in, and experience with the lab techniques can be improved (Maldarelli *et al*., 2009). Implementing online vLab demonstrations with interactive components can help students to understand difficult and seemingly abstract concepts. Evidence from a systematic review and meta-analysis, including 23 articles, found vLabs to provide improved student affective and psychomotor skills (Udin *et al*., 2020). However, this brought together a range of vLab modalities consisting mainly of 3D flash player videos, which lack the opportunity to build in enquiry-based learning platforms. Many studies also lacked comprehensive assessment of students conceptual understanding and science processing skills (practical tactile skills). Although limited, from this evidence there is a clear need for the integration of a more immersive student experience, avoiding exclusively didactic teacher to student transmission of knowledge (Esnard and Mohammed, 2019). It is also critical that any implementation of a vLab learning environment remains accessible to all students. One way to achieve this is to provide institutional access through a learning platform (Canvas) link and make this accessible on university computers. The very nature of a vLab or online learning tool should enhance accessibility. They can be replayed and rehearsed as the students wish until they feel competent at the exercise. However, simply providing access to a vLab system cannot be expected to improve students' outcomes passively and requires teacher input and careful integration with existing learning modalities

(May *et al*., 2013). Thus, vLabs should be seen as an augmentation tool to 'traditional' taught content and in-person lab practicals (Unsworth and Posner, 2022).

Research to understand the impact of vLabs increased during the COVID-19 pandemic as more online teaching was required. From this, it was evidenced that multiple forms of remote teaching should be combined for a more positive student experience. For example, combining vLabs with data analysis, literature review and science writing and encouraging critical discussion in journal club type sessions (Brandt and Novak, 2021, Chandrasekaran, 2020). From these recommendations, it is still apparent that learning outcome assessment and quality assurance needs are still not fully monitored in the combined use of vLabs with other methods of delivering teaching. It would be uncontested that practical lab experience translates into real-world applications outside of academic study. However, whether implementing vLabs would facilitate this is not known and is perhaps hard to measure accurately. More recent research has indeed shown improved test results from students who engaged with vLab activities over those receiving textbook-based instruction (Ye *et al.*, 2016). By introducing a blended learning approach to laboratory practicals, students were facilitated to work independently in a self-paced learning environment, prior to face-to-face instruction. This 'flipped learning' style, whereby students first complete tasks in their own time prior to more formal teaching, can significantly improve both student satisfaction, lead to higher summative marks and improve outcomes for those with reasonable adjustments (Chandrasekaran, 2020, Brewer and Movahedazarhouligh, 2018).

However, integrating vLab learning into undergraduate courses is not without limitations. It is important that students are still fully supported in laboratory practical sessions, and it should not be assumed that completing online tasks to a high standard replaces the need for careful guidance from teachers. The gamification of laboratory practicals and running of virtual experiments (with no 'real' consequence to mistakes) could take away from the care and precision needed in the physical laboratory. The health and safety implications or poor laboratory skills are very real for in-person teaching, and so consideration for this must be given when moving from vLab learning to the real-life setting.

Whilst one motivation for implementing vLab platforms into undergraduate study could be to reduce costs of physical laboratory experiments, they are not without cost themselves. In fact, integrating vLabs into courses with a minor practical component or with large student numbers may not be feasible, costing in the range of £40-90 per student per year depending on content access levels and platform selected. Although there is growing evidence for improved student outcomes and experiences associated with implementing vLabs into undergraduate programmes, these costs may not be fully justified for all courses and will likely limit its integration.

Conclusions

Delivering high quality, accessible and purposeful laboratory practical sessions remain an important feature of undergraduate science courses. Such sessions can enable practical and problem-solving skills development and the application of theory to 'real-world' settings. The incorporation of online learning materials in the form of virtual demonstrations, pre-recorded demonstrations and linked assessments that enable students to prepare and engage with in person practical sessions can significantly improve student experiences. However, it is important that teachers support and encourage student engagement with online platforms to make sure proper understanding is achieved, especially regarding lab safety. Additionally, data on the cost-benefit of providing institutional/ course level access to vLab software is also lacking, which may limit its integration into undergraduate courses currently.

Ethical Statement: Data collected for use in figure two has been fully anonymised and processed as secondary data by the lead author.

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